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PASSENGER TRANSPORTATION APPLICATIONS
OF THE AIRSTOP RESTRAINT SYSTEM

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Final Report, Aircraft Applications Addenda
to NASA Contract NASw-877

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FOREWORD

This final report is prepared in accordance with the requirements of Contract NASw-877, "A Pilot Compartment Airbag Restraint Program," with its addenda extending the work to the aircraft passenger restraint problem, between the National Aeronautics and Space Administration and the Martin Company. The final report on the spacecraft applications of airbag restraints, briefly summarized in this document, was submitted to NASA in July 1964, and is available as Martin Engineering Report 13551 "Pilot Compartment Airbag Restraint Program, Final Report," by Carl Clark, Carl Blechschmidt and Fay Gordon. A further application of the airbag restraint concept as an inflated "Airlitter" for the transport of the injured was supported as an additional addendum of Contract NASw-877, and will be reported on as a third "final report" on this contract. The applications of airbag restraints to automobiles, high speed trains and other advanced transportation systems are not yet supported by contract, but are briefly discussed in this report.

The overall contract monitoring by NASA was provided by Mr. John Fuscoe, Code RBB, Human Factors and Biotechnology Division, Office of Advanced Research and Technology, NASA Headquarters. This aircraft application work was primarily monitored by Mr. John Enders, Aeronautics Division, Office of Advanced Research and Technology.

This program was conducted under the program management of Dr. Carl Clark, with Mr. Carl Blechschmidt as Technical Director. Acknowledgment is made for the excellent assistance of Mr. Fay Gordon, structural design and test, and computer analysis; Mr. Frank Reed, instrumentation; Mr. Joseph Dausen, pneumatic systems; Mr. Cazimir Czyryca, seat and bag construction; and Dr. Armond Gold, physiologist.

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We pay special acknowledgment to Hugh DeHaven, for his long efforts to help us indeed survive "survivable" accidents; to Dr. Bo K. Lundberg, Director General, Aeronautical Research Institute, Bromma, Sweden, in appreciation for his forceful concern for aviation safety; and to Assen Jordanoff, who apparently early in 1952 had the first organized concept of the use of airbags for crash protection.

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SUMMARY

A perspective of human transportation fatalities is presented. An historical review of certain human crash restraint concepts and of the airbag restraint concept is presented. The results of the first Martin airbag restraint program and of the spacecraft and "Airlitter" applications are summarized. The aircraft airbag restraint program (NASA Contract NASw-877 addenda) is reported, including Martin swing and drop tests, the DC-7 crash test of April 1964, the C-45 crash test of November 1964, the C-45 crash test of April 1965, the NASA-Ames turbulence load isolation tests and the FAA catapult track tests of November 1965. Potential applications to automobiles, high speed trains and other advanced transportation systems are briefly discussed.

It is concluded that the aircraft airbag restraint concept of providing the passenger with broad controlled deformation surfaces in all directions, with transparent chest and foot bags inflated before every takeoff and landing and after any inflight emergency, can provide the passenger with significant load isolation and protection in the event of a crash or severe turbulence. Following the crash, the airbags and the airseats would be automatically deflated, very significantly increasing the ease and speed of all passengers leaving the aircraft. A preliminary automatic deflation control system has been successfully tested. It is emphasized that engineering development of this "airstop" restraint system has not yet been carried out, although it is the view of those involved with this contract and the contracting agency that the system is now ready for such development, with final weight possibly not exceeding the weight of present seat systems. The airstop restraint system appears engineeringly feasible and can further reduce the hazards of flight. Its development must await further support.

SYMBOLS

$+G_x$	Acceleration of the body forcing the heart back toward the spine--also called "eyeballs in"
$+G_y$	Acceleration of the body forcing the heart to the left in the chest--also called "eyeballs left"
$+G_z$	Acceleration of the body forcing the heart down in the chest toward the pelvis--also called "eyeballs down"
$+g_x$	Displacement acceleration of the vehicle, increasing speed in a forward direction
$+g_y$	Displacement acceleration of the vehicle, increasing speed to the right.
$+g_z$	Displacement acceleration of the vehicle, increasing speed down.

Note that the physiological accelerations, G , include gravitational effects: the standing man (on earth) experiences $+1G_z$. The displacement acceleration, g , does not include gravitational effects: a vehicle at rest experiences $0g$. Both the physiological and displacement accelerations are presented as multiples of the earth surface gravitational acceleration, g (32.2 fps or 9.8 m/sec).

I. INTRODUCTION

A. A PERSPECTIVE ON HUMAN TRANSPORTATION FATALITIES

With increasing travel, increasing protection is required if the numbers killed by accidents in travel are not to limit further growth in travel. Ancient man, one hundred thousand years ago, perhaps walked thirty kilometers a day (and some housewives say they still do this), or over ten thousand kilometers a year, with the expenditure of the few hundred watts of his own awake effort. His walking speed might have been about 1.5 m/s; the athlete in the 20 m dash might reach 10 m/s. His hazards of travel were more his neighbor's meat pit or his intended dinner's teeth and claws than collision, although occasionally he would fall out of a tree or off a cliff.

Today, man expends vast amounts of energy not his own for travel. The high school boy may roar off with the quarter of a megawatt of his dad's Cadillac. The movie starlet may have a 20 megawatt jet aircraft at her command. The astronauts command at launch 10 and soon 100 gigawatts (the gigawatt is 10^9 watts; the total electrical generation capability of the United States is near 100 Gw). If the astronauts experienced the mileage death rate of the automobile, there would be fatalities on every few trips. As we improve means of travel, and each of us takes longer trips, we must improve the safety per kilometer traveled if we are to have an acceptable probability of surviving the trip.

At present, this expansion of travel is just beginning. In 1962, the average U. S. motor vehicle traveled 9,635 miles (15,500 km),¹ half in urban travel. We have on the average, hardly more than motorized the travel of our early hunting ancestors, trading the great saving of time for the other sacrifices to the automobile, including crashes. The average U. S. total power consumption is near 10 kw, compared to a world average near 1 kw. Yet some of us already are megawatt people, commuting every few days across a continent or an ocean and a few for brief periods have been gigawatt people. (Poor Pharaoh, lashing four million slaves, "controlled" only about one gigawatt, but his pyramids may last longer than our missile bases.) Although the 1961 average automobile trip to work was only 6.4 miles (9.4 km)² and the average auto trip for any reason was 8.0 miles (12.9 km),² we expect this to grow rapidly. Mankind is just getting into the "infectious period" of very rapid growth of his use of technology.

Table 1 describes the major means of powered travel for the United States and their hazards. Table 2 gives the totals killed in relation to their causes of death.

TABLE 1
United States Means of Transportation
(preliminary values--see footnotes)

Method	U.S. Number of Vehicles	Millions of Passenger mi/yr	Death per 10 ⁸ Passenger Miles	Passenger Terameters per Year ^a	Deaths per Passenger Terameter	Average Trip (km)	Probability of "my" Death per Trip
Passenger car	66,589,000 ^c	1,070,000 ^d	2.2 ^e	1700.	14	13 ^f	1.8×10^{-7f}
Walking	190,000,000	204,000 ^g	9	330.	57	0.02	1×10^{-9}
Intercity bus	75,500 ^h	57,700	0.23 ⁱ	93.	1.4	100	1.4×10^{-7}
Air carrier aircraft	2,200 ^j	58,400 ^k	0.34 ⁱ	94.	2.1	1000	2.1×10^{-6}
Train cars	12,000 ^l	18,520	0.07 ⁱ	30.	0.42	100	4.2×10^{-8}
General aircraft	114,000 ^j	2,600 ^m	31	4.	190	100	1.9×10^{-5}
USAF military aircraft	15,000 ⁿ	2,700	11	4.	68	100	6.8×10^{-6}
Spacecraft	4 ^o	13	0.029	0.03	0.18	2.8×10^6	0.5×10^{-3}

^aThe terameter (Tm) is 10^{12} meters or a billion kilometers, in the international terminology.³ The total travel of this column is 2255 Tm, which gives an average U.S. travel for 185 million people of 12,000 km (7600 miles). Since values given in this table are for slightly differing years, this value is, of course, approximate.

^bIn the United States, travel death rates are commonly given in deaths per 100 million passenger miles. In this unit, values below one are often attained. Lundberg⁴ has recently used deaths per billion passenger miles; we suggest the international equivalent, of deaths per billion passenger kilometers or simply deaths per passenger terameter, as the appropriate international unit for travel death statistics. Note that deaths per passenger Tm = 6.22 times the number of deaths per 10^8 passenger miles. To further emphasize that death rates are large, it might be considered that rates be expressed as deaths per passenger terakilometer. In this scale, the auto death rate becomes 14,000, a much more shocking value than $2.2/10^8$ passenger miles.

^cReference 1, for 1962. Reference 2 estimates 75 million cars by 1966.

^dReference 1, for 1962, gives 6.3×10^{11} automobile mi/yr, and Ref. 2 gives an average car occupancy of 1.7.

e

This value is for deaths of occupants per 100 million passenger miles in passenger cars or taxis. It excludes pedestrian deaths but includes drivers. The National Safety Council data, presented in annual "Accident Facts", include such a value, but generally stress the higher number for total deaths involving all motor vehicles per 100 million motor vehicle miles. Reference 5 gives the 1963 passenger miles for passenger auto and taxi occupants as 1.24×10^{12} , and the death rate as 2.3 deaths (of occupants) per 100 million passenger miles (excluding pedestrians). These distinctions between vehicle miles and passenger miles, all motor vehicles or just passenger cars, and deaths with or without pedestrians and crew must be carefully observed in reading crash statistics. We stress again that Table I is preliminary and approximate.

f

Reference 2, for 1961, gives the average automobile trip as 8.0 mi. The rest of this column are our guesses. The probability of a specific individual passenger's death ("my death") per trip equals the deaths per passenger terameter times the trip length in terameters. The probability of any passenger's death on the trip is this value times the number of passengers on this trip. More accurate values here, for the probability of "my" death in a planned trip as a vehicle occupant, would use distance death rates excluding pedestrians or those outside the vehicle killed in the crashes. Hence for cars we get for the probability of "my" death per trip 1.8×10^{-7} , which sounds safe enough were it not for the fact that we may make the equivalent of perhaps a quarter of a million average trips in a life time.

g

The walking distance figure assumes the average person in the United States walks three miles a day. Using the National Safety Council "Accident Facts", if we say that deaths while walking include the 9000 pedestrian deaths due to motor vehicles (in 1964), and half of the 19,300 deaths (1963) due to falls (73% of which occur for people over age 65), the walking death rate becomes 9 deaths per 100 million miles walked or 57 deaths per terameter of walking. Assuming the average walk is 20 meters, the probability of death during this "average" walk is 1×10^{-9} . Actual values vary extensively with place of walking, age of the walker, etc. If these average values have any meaning, it is astounding to see this indication that walking is more dangerous than driving over the same distance.

h

Reference 1, for 1962.

i

Reference 5, for 1963. These values are for deaths of passengers within the bus or air carrier aircraft or train, and do not include deaths of pedestrians or others outside these vehicles killed in crashes. Train deaths do not include employees on duty or trespassers. Aircraft deaths include the crew.

j

Reference 6, 1963. Hoekstra, Ref. 7, gives the 1965 small United States aircraft number as "over 90,000."

k

Reference 5, for 1964. The domestic United States air carriers had a 1964 mileage death rate of 0.24/100 million passenger miles. (See the errata sheet sent by the Aviation Safety Center for their table, page ii of the reference.) The non-Communist world-wide aircraft death total in 1964 was 691, for a rate of 0.64 deaths per 100 million passenger miles, or 4.0 deaths per passenger terameter.

l

World Book, 1960.

m

Reference 6 gives the general aviation fatalities as 794, the fatal accidents as 437, and the fatal accident rate per 100,000 flight hours as 3.4 in 1961. Hence there were 12,900,000 general aviation flight hours in 1961. Assuming 100 mph, and two people per plane (our guess) on the average, this gives about 2600 million passenger miles, and hence a mileage death rate of very roughly 31 per 100 million passenger miles in 1961. FAA release 64-33 states that airport towers at 277 airports reported 31 million take-offs and landings in 1963, a new record.

n

Reference 8 gives the 1961 USAF fatalities as 297 for 6.8 million flight hours. Assuming an average speed of 200 mph and crew of two, this gives a very rough estimate of 2700 million passenger miles per year, and a mileage death rate of 11 per 100 million passenger miles. Note that Navy and Army aircraft figures are not included here. Hoekstra gives the 1965 active military number as 25,000. Colley and Kiel, Aerospace Med 36:636, 1965, state that there are 30,000 military aircraft, involved in 1300 accidents per year, resulting in 500 deaths.

o

Four Gemini flights are planned in 1965, we understand of 1, 4, 8, and 2 days. At an orbital speed of 18,000 mph, and with a crew of two for each flight, this gives 13 million United States space passenger miles estimated for 1965. The "average trip" is taken as four days. If the crew safety probability is to attain 0.999, as it is for the Apollo mission, excluding meteorite, radiation and crew error hazards,⁹ or less than one death in one thousand missions, the two man spacecraft would fly at $10^3 \cdot 2.8 \cdot 10^6$ km, or 2.8 Tm between deaths, or attain a death rate of less than 0.18 per passenger Tm, a distance death rate of about 1/100th of that of the automobile. (Later note: Five Gemini flights were actually carried out in 1965, of 1, 4, 8, 14 and 1 days, each with two men to give 23 million space passenger miles by the United States in 1965, without a fatality. Mankind now has a total of 79 man days in space (58 man days by the U.S.), for a total of 33 million space passenger miles, without a reported fatality. It is emphasized that the space mileage death rate is based on estimated vehicle reliability, not on actual deaths thus far. Hopefully our performance will be even better than 1 death per three billion space passenger miles.)

TABLE 2

Births and Deaths
(approximate values for any year)

	<u>People</u>	<u>Rate</u> <u>(per 10⁵ people)</u>
Population (1963)	189,000,000	
Population (1964)	191,000,000	
Births/year (1964)	4,054,000	2120/10 ⁵ people
Deaths/year (1964)	1,801,000	941/10 ⁵ people
Deaths/year (1963)	~1,800,000	
Heart (1963)	707,830 ^a	380/10 ⁵ people
Cancer (1963)	285,362 ^a	150/10 ⁵ people
Stroke (1963)	201,166 ^a	110/10 ⁵ people
Accident Deaths (1963)	104,300 ^b	56/10 ⁵ people
Auto (1963)	43,600 ^b	23/10 ⁵ people
Auto (1964)	47,700	25/10 ⁵ people
Home (1963)	29,000 ^b	
Work (1963)	14,000 ^b	
Train (1964)	13 ^c	
Intercity Bus (1964)	130 ^c	
Scheduled U.S. Airplanes (1964)	200 ^c	
General Aviation (1961)	794 ^d	
USAF Military Aviation (1961)	297 ^e	
Other Accidents (1963)	~16,000 ^b	
Other causes of death	~500,000	

^aRef. 10

^bNational Safety Council data. See "Accident Facts"

^cRef. 5

^dRef. 6

^eRef. 8. See also Colley and Kiel, Aerospace Med, 36:636, 1965.

The last column of Table 1 should be emphasized. Since trips by different means of transportation are of varying lengths because of the varying amounts of power we are willing to spend, our safety emphasis should be on probability of death per trip, or perhaps per trip day, not per mile. In these terms, flying in aircraft or spacecraft for long distances is not as safe as driving an automobile for short distances, and appropriately should be made safer. But at these low levels, it is not death rates which we are aware of but, through wide news communication, the absolute numbers of dead in each crash news event. Thus the newspaper reports of a major aircraft crash, killing perhaps 100 people (and this number may grow to over 500 for the giant planes of the next decade, of the Antonov-22 and C5A types) is far more striking for us than the daily toll killed for automobiles of two or three in each local area, though we are now killing some 140 people every day on the highways of the United States.

Although there were 81 million airplane "passengers" in 1964, many of these were the same persons flying more than once. Perhaps 85% of the American public has never flown, and fears to do so in considerable part. And if we do not further improve travel safety, this fear can only grow. Thus,

Dr. Bo K. Lundberg,⁴ Director General of the Aeronautical Research Institute of Sweden, predicting the great expansion of air travel, also predicts a major

air disaster (world-wide) every day by the end of the 1980's if the distance death rate does not decrease. He urges emphasis on safety with thoroughly prepared aircraft advances in preference to the development now of the supersonic transport. Lundberg would like, by making safety the major development effort, to attain a distance death rate of commercial aircraft of better than 0.05 per 100 million passenger miles (or 0.31 deaths per passenger terameter) by 1985. He states, "Whenever a risk can be foreseen, it must be reduced to a very much smaller level than at present." We show in this report that inadequate passenger restraint is one of these risks and that the airstop restraint can significantly reduce this risk.

Today, there are quite enough transportation deaths, indeed far too many, for us to consider that we have a good safety record because of a "low" distance death rate. Let us honor the grand old men who have brought us so far in safety. Then let us call today's transportation death rates shockingly high, and get on with our business of increasing safety. Our safety goal must become one of ensuring no more deaths per year in each mode of transportation than now occur, however much the distance traveled expands--and indeed to reduce the needless slaughter now occurring. Table 3 shows how we are not succeeding in this goal; although the distance death rates are going down, the total numbers killed are increasing.

TABLE 3
A Decade Comparison of Transportation Fatalities
(From Ref. 5, 1964 and 1954 editions)

	<u>Deaths</u>		<u>Millions of Passenger Miles</u>		<u>Deaths per 10⁸ Passenger Miles</u>		<u>Deaths per Passenger Terameter</u>	
	1953	1963	1953	1963	1953	1963	1953	1963
Scheduled								
U.S. Aircraft	86	121	15.3k	52.6k	0.55	0.23	3.4	1.4
Automobiles (passengers)	22.6k	26.8k	0.8M	1.2M	2.8	2.3	17	14

B. COMMERCIAL AIRCRAFT ACCIDENTS

We should inquire how many more aircraft passengers might survive if there were improved restraints. There is a common picture, supported by the detailed news pictures of wreckage from an occasional crash, of the airplane hitting the ground and disintegrating in a ball of fire. However, this is not the only crash condition. Hoekstra and Hoover⁷ report that only approximately 15% of the total air carrier accidents involve fatalities. Hugh DeHaven survived a mid-air collision in World War I in which three other men died because their heads hit surrounding cockpit rigid structures, whereas DeHaven's head, possibly because he was shorter, had missed this structure.¹¹ In later years, he strongly emphasized the study of the "survivable" accident (a term due to Hasbrook, one of his co-workers), meaning one in which the area of the passenger is not totally destroyed by impact, whether or not the particular passenger actually survives. Townsend et al.,¹² describing major U. S. air carrier accidents of 1959 and 1960 (including only one accident with no fatalities), note that of 872 people in these 20 accidents, 178 survived (in eight accidents) and that for 233 (five accidents) pathology examinations were not possible due to extreme disintegration. The authors do not give the percent of survivability at the passenger and crew locations in these crashes, but it would be between the 20% who did survive and the 75% who escaped extreme disintegration. If the passengers are not thrown about onto rigid structures, and hence they receive accelerations no more than those of the intact cabin structure, they too can survive. The fact that the passengers don't survive in this category of fatal but "survivable" crashes is a deficiency of our application of even the established "delethalization" principles (another term by Hasbrook). As Mohler⁶ puts it, "In the long run it will pay (in terms of decreased mortality and morbidity and a decreased fear of flying in the general population) the aviation industry to incorporate features in all new aircraft which will protect the occupants from impact injury."

Townsend et al.¹² found for the 1959 to 1960 commercial fatalities that the majority of injuries "consist of fractured skulls and fractured lower legs which result from the jackknife motion of the body when it is retained in the seat by the lap-type safety belt." Many seats were torn loose. "It has been proved that as restraint area increases, the likelihood of injury occurring decreases." They suggest among other things that seats be made stronger than the present -9G_x failure levels, and the possibility of installing leg retention devices.

They note fire in 3 of the 15 accidents, (excluding the 5 "extreme disintegration" crashes) with 28 killed and 68 surviving. Severe leg injuries were found in 11 of those killed in the fire accidents. Fire can indeed make none survive a crash which, from the impact condition, is "survivable." Yet, most of those who survive fires do so by walking out before the fire spreads; it is important to improve their ability to walk out by protecting them through the impact event and by improving speed of egress along with improving fuel retention tanks and speed of fighting crash fires.

Then how many more might be saved by improved restraints? Of those killed in survivable commercial accidents with major aircraft damage, some will be killed by fire (less than 20%), even if uninjured. But the majority are killed by impact, and the majority of these could expectedly be saved by the operation of a load isolation restraint system.

Doyle and Roepe¹³ review U.S. air carrier accidents from 1954 to 1964 of land planes terminating their flights in water. Of 1266 passengers and crew involved, 720 (56.9%) experienced fatal injuries, of which 542 deaths were in accidents with no survivors (although some lived briefly, and might have survived with improved protection); 647 of the 720 died of impact forces, 71 died of drowning and/or exposure, and two died of shark attack and heart attack. Improved impact protection could significantly cut this toll and let indeed survive more of those in "survivable" accidents. A similar impression is gained in examining, for example, the 1961 tabulation and description of member country air carrier accidents of the International Civil Aviation Organization,¹⁴ with the following subdivisions:

1961 ICAO Commercial Air Transport Accidents¹⁴

20.4% during take-off

27%--involved control system difficulties

29.6% en-route, including many of the serious accidents

37.5%--collisions with rising terrain

13%--engine tearaway

13%--wing failure

50% during approach or landing

56%--collisions with the terrain or objects thereon, including
15% undershoots

18%--due to stall or loss of control

The possibility exists for generalizing the acceleration time histories of aircraft crashes of various types, as we have attempted for automobile crashes¹⁵ and as Preston and Pesman¹⁶ classically began for aircraft, in order to estimate the acceleration conditions now associated with loss of life, and the possibilities of increased survival by improved restraints and cabin design.¹⁷ This will be discussed further in Chapter IV, Analysis. The point is made here, however, that there are lives to be saved by improved crash protection and egress

improvement and fire suppression; one should not accept an attitude that the crashes with most deaths are nonsurvivable and hence nothing can be done about them. Indeed look at press photos of the wreckage of the TWA Constellation which crashed after a mid-air collision and loss of aerodynamic control except engine speed on December 4, 1965. With one wing and tail gone and the cabin broken in several places and opened almost along the entire roof, one might suppose that this was a nonsurvivable crash. Yet 50 of the 54 on board survived, in some measure because they were able to get out through the broken cabin openings as well as the regular doors before fire engulfed the wreckage. The cabin roof was opened mainly by the fire rather than impact.

The classical aircraft fire analyses were made by Pesman,¹⁸ showing the need for selective directions of aircraft evacuation depending on fire positions and wind direction, with some fires following moderate severity landing accidents reaching survival limits in as little as 50 seconds.

Turnbow et al.¹⁹ also emphasize many aspects of improved aircraft safety design. They suggest that the 1956 National Aircraft Standards Committee Specification No. 809 of transport aircraft seat strength limits for a 190 pound passenger of $-9.0G_x$, $+3.0G_y$, $-2.0G_z$, and $+6.0G_z$ be increased to -20 to $25G_x$ (with the addition of energy absorbing seat backs), $+15$ to $20G_z$, and ± 10 to $15G_y$. The airseat design, even in the crude latex and canvas prototype thus far tested, has already been shown to function to these G_x and G_z limits under dynamic conditions.

C. MILITARY AIRCRAFT ACCIDENTS

Looking again at Table 2, more are killed in military aircraft than in commercial aircraft. Lentz²⁰ reports on 420 "controlled crash" Air Force aircraft accidents from January 1960 to July 1962. These survivable accidents are 40% of the total of all major Air Force Accidents (with major or complete aircraft destruction) in this period. These include trainers, fighters (half the accidents), bomber-cargo planes, liaison planes, utility aircraft and helicopters, but no passenger aircraft. Hence, these are higher performance aircraft, and a decreased crash survivability is understandable. Fire occurred in 36% of these survivable crashes, and 67 of the 72 killed in these crashes were in such fires. In general, shoulder straps as well as lap belts were in use in these crashes, perhaps explaining why more were not injured. Of the 1226 people involved in these crashes, 94% survived. This is such a good record that one should re-examine the other 60% of the major accidents. Some of these were perhaps "survivable," i.e. with crew or passenger areas intact in spite of major aircraft damage. One should examine these additional cases to see why there were not more survivors. One of our criteria of accident examination has been that if anyone survives in a plane crash one should very carefully examine the crash to see why others did not also survive (in the grand DeHaven tradition).

However, examining the 72 fatalities of these survivable Air Force accidents, of the five killed when there was no fire, one was struck by a propeller and three drowned. Of the 67 killed in accidents with subsequent fires, 46 fatalities were attributed primarily to crash injuries. Col. Lentz notes, "While deaths were attributed to impact injuries, it must be conjectured that, were it not for the fire, at least a few of these people might have been saved." This is true, and the helicopter rescue and fire suppression work that he describes are very important. But we emphasize that a man can be killed by fire without an obvious impact injury, yet the confusion or even unconsciousness caused by the impact can delay his escape until it is too late, and Col. Lentz notes this point. Indeed, Col. Lentz describes a T-33 crash in which the co-pilot is momentarily unconscious, then crawls out of the wreckage, sustaining severe burns over 45% of his body but with no impact injuries described. The pilot did not crawl out; he had no obvious impact injuries and his death is attributed to fire. Yet might not he too have been unconscious--for just a little longer than the co-pilot, with the real cause of death an impact sequela?

Air Force Accidents with Major Aircraft Damage (after Lentz²⁰)

- (1) At least 40% are survivable.
- (2) Of the 72 fatalities in these survivable accidents examined, at least 64% are due to major impact injuries, followed by fire. (Not all of these would have survived if they had sustained no impact injury, by restraint isolation.)
- (3) Of the 29% deaths attributed to fire, some might have escaped if not confused by the impact event.

It is difficult to evaluate the significance of a load isolation restraint for these military aircraft accidents. Apparently they are less survivable than commercial accidents, and fire suppression is more important. But possibly as many as half of those killed in survivable accidents could have lived to escape with the operation of a load isolation restraint and airseat deflation system, in spite of the reduced space for this system in many military aircraft.

Moseley et al.²¹ give data on 8416 occupants involved in major USAF aircraft accidents in 1953 and 1955, with 18.7% fatalities, 5.2% with major injuries, and 76.1% with minor or no injuries. Note that for these major aircraft accidents, the percent surviving is 81%; the percent survivable may be over 90%. They state, "The force of deceleration was responsible for 87.7% of all fatal and major nonfatal injuries, while the remaining 12.3% of injuries were due to fire, to protruding, intruding, or hurled objects and to other causes, including drowning." Indeed, of the 1572 fatalities, burns accounted for the primary fatal injury of only 105 (6.7%) whereas impact traumata are the primary injuries of all but 158 of the rest.

Beyer and Bezreh²² review impact studies of the U.S. Army. They note that 97% of Army aircraft accidents (pre-1961) may be considered as survivable, and that as many Army pilots have been killed in survivable accidents as in nonsurvivable ones. Seventy-five percent of the spinal column injuries occurred in rotary wing aircraft accidents, with vertical crash forces, a category which will expectedly further grow in importance with the increase of VSTOL aircraft. Our deformable airseat design provides down-load protection. Turnbow et al.¹⁹ recommend increasing the 1956 National Aircraft Standards Committee Specification No. 809 for the strength of rotor-craft seats with a 190 pound occupant from $-4.0G_x$, $+2.0G_y$, $-1.5G_z$, and $+4.0G_z$ to $-45G_x$, $+25G_z$ (with vertical energy absorber), and $+45G_y$ for military helicopters.

D. GENERAL AVIATION ACCIDENTS

We would expect the light aircraft General Aviation experience as to percent survivability to be like the 97% of Army Aviation.²² Hoekstra and Hoover⁷ report that about 10% of the general aviation accidents involve fatalities. Many of these deaths could have been avoided by better use of safety design and safety equipment even if the accident had still occurred. A study of these cases shows the need for improved tie-down of seats and passengers.²³ Including more recent cases, Pearson²⁴ observes, "Injuries were not to be attributed to primary crash forces per se but rather to factors that were directly a function of such forces, principally structural collapse, tie-down failure, and flailing of the head and extremities against injury-producing structures within the occupant's environment." He concludes, "Effective tie-down is of considerable value in reducing injury, even at high angles of impact and at impact velocities exceeding 90 miles per hour. Its value is further enhanced when the shoulder harness is used."

Reals et al.²⁵ provide additional analysis on 178 deaths (1%) for which adequate autopsies were available of the 15,076 killed in light aircraft in 8888 fatal accidents between 1944 and 1962, during which 17 year period there were 91,119 general aviation accidents. This supports the figure of 10% of these accidents involving fatalities and emphasizes the inadequate extent of autopsy analyses being made. They state, "Visceral trauma is a major factor in deaths in this category of aircraft, as are head injuries and incapacitating fractures. Complete autopsy examination of all victims of air crashes are of utmost importance in the promotion of general aviation safety." Of the 148 cases with sufficient material available to permit assessment of skeletal and visceral injury, 51 had been burned, but only seven of these were alive when burned, as shown by carboxyhemoglobin analysis or anatomical evidence of having survived the crash. They show 10 with severe brain damage but no evidence of skull fracture, and 26 with skull fractures but no gross evidence of brain injury. "Since clinical histories and accident data were not available, we cannot rule out concussion of varying degrees which may have been incapacitating."

A remarkable series of experimental aircraft crashes were carried out by Pinkel, Pesman, Preston, Eiband, Simpkinson, Black and others at the NACA Lewis Flight Propulsion Laboratory in Cleveland during the early 1950's. Light plane crash results at 42, 47 and 60 mph are reported by Eiband et al.⁸⁴ For the tubular frame-fabric design of particularly pre-1950 light aircraft, progressive rearward crumpling of the structure limits longitudinal loads at the passenger compartment to between -26 and $-33G_x$, independently of impact speed, although crash duration increases from 0.02 to 0.07 sec. The higher crash speeds cause crumpling further back, with collapsing of the passenger compartment (at least at the front seat) becoming severe for 60 mph head-on crashes (into a hill at 55°).

Dummy chest loads, however, increased with speed from $-32G_x$ for the 42 mph crash to $-50G_x$ for the 60 mph crash, an effect of restraint stretching and dynamic overshoot characteristics. With lap belt and shoulder harness, the authors consider the 60 mph crash into a 55° hill to be tolerable by a human in the rear seat. Restraint loads of 5800 pounds were found at 60 mph. They state, "In order to avoid injury-producing contact when only seat-belt restraint is used, the space in front of the occupant must remain free of obstacles for a distance approximately equal to the length of the torso from the hips to the top of the head (plus seat-belt elongation)." This is given as 31 to 45 inches forward of the seat which "must remain free of any solid, sharp or unyielding protuberances." "The maximum total restraining forces recorded indicate that, when seat-belt restraint is used alone, these belts should be capable of withstanding higher breaking loads than those presently in use." These same points apply directly to the automobile as well.

Pearson²⁴ indicates that if restraints hold, even over 90 mph crashes may be survived. The "survivable" crash is not a sharp boundary, as Table 4 shows.

TABLE 4

Relation of Light Aircraft Environment Damage to Fatality (Pearson²⁴)

<u>Cabin Condition</u>	<u>Percent Fatal</u>
Intact	1
Distorted	14
Partly Collapsed	27
Collapsed ("Unsurvivable")	80

It would be interesting to have the percent of total number of accidents in each of these categories. He also discusses the importance of angle of impact and stopping distance. Although aircraft accidents may involve higher speeds than

automobile accidents, the crash is usually spread over a longer distance, reducing accelerations. Pivoting of the aircraft fuselage and crumpling of the nose may provide considerable load relief, particularly in larger aircraft toward the back of the airplane. Typically the airplane experiences a series of impacts onto the ground, no one of which involves a velocity change as large as may occur in a severe automobile crash.

Pesman and Eiband¹⁷ state, "The collapse of seats and other structures can trap occupants and prevent escape or hinder rescue even though the occupant is not severely injured. Attachment fittings for cabin equipment can fail and allow the equipment to become lethal missiles . . . A human being can tolerate decelerative loads of 45G's perpendicular to the spine, and 20G's of compressive load parallel to the spine if adequately supported. Additional restraining harnesses to keep the spine in proper alignment may hold the occupant in a better position to withstand vertical blows."

With this background, it is clear why Turnbow et al.¹⁹ recommend increasing the 1956 National Aircraft Standards Committee Specification No. 809 for normal and utility aircraft seats with a 190 pound occupant from $-9.0G_x$, $+3.0G_y$, $-3.0G_z$, and $+7.0G_z$ to -30 to $40G_x$, $+20$ to $25G_z$, and $+20$ to $25G_y$ for light fixed wing aircraft. With these authors¹⁹ representing the Flight Safety Foundation, FAA, and CAB, it will be interesting to see how long it will be before their seat recommendations are applied as new standards for the aircraft industry. They also recommend the shoulder harness for all seat occupants.

We feel that with restraints meeting the Turnbow et al.¹⁹ specifications, over half of the 883 people killed⁵ (in the 459 general aviation fatal accidents of 4922 total accidents of some 81,000 aircraft in 1964; FAA data) would have survived."Accident Facts," 1965, quotes the CAB that there were 1056 deaths in 5070 accidents in general aviation in 1964. Note that some 5% of the general aviation aircraft have accidents each year. Clearly, the aircraft should be designed with particular consideration of this accident event. If the percent survivability in light aircraft is indeed the 97% estimated for Army aircraft,²² some 280 of these people were in "nonsurvivable" accidents and remember that Pearson showed that 20% of these still survived. Assuming that we are unsuccessful in changing the number of accidents, to reduce our deaths from 883 to 230 will require not only improvements in impact protection but also in fire suppression, rapidity of escape, survival after escape, etc. Of all of these factors of survival, impact protection is the most important.

E. AUTOMOBILE ACCIDENTS

Although the emphasis of this report is on aircraft restraint, and other of our reports deal with the automobile,¹⁵ it is indeed in the automobile where most lives can be saved of those now lost in transportation. All of us working in crash safety have a responsibility to look for application of our work to this tragedy, which may touch not just the 1% of us who fly in military aircraft, or the perhaps 1% of us who fly in noncommercial civilian aircraft, or the perhaps 15% of us who fly in commercial aircraft (and for most of these, flights are not daily events) but the tragedy which may touch all of us who drive in cars most every day.

There are now some 90 million motor vehicles (82% are passenger cars, 16% trucks) in the United States, with an annual new production of some 9 million cars and an average car "life" of about 10 years. By rounding up, in terms of 1965 trends, the 1964 values from the National Safety Council Accident Facts²⁶ (which are for the most part estimates scaled up from smaller samples) and adding two "total injured" estimations, we approximate 1965 values shown in Table 5.

TABLE 5

1965 Motor Vehicle Transportation Toll (approximate estimates)

	<u>People</u>	<u>Accidents</u>	<u>Drivers Involved</u>	<u>Direct Cost</u>
Killed (19% pedestrian)	50,000	40,000	60,000	} \$6 billion (Death and disabling injury costs)
Permanently Disabled	150,000			
Injured (disabled)	2 million	1.2 million	2 million	
Total Injured (medically attended)	5 million	3 million	5 million	
Total Injured or Sore (medical complaints)	10 million	8 million	10 million	
Reported Property Damage				
With injury (medically attended)	(8 million people involved)	3 million with medically attended injury	5 million	} \$3 billion (Property damage costs)
Without injury (damages greater than \$50)	(30 million people involved)	11 million without injury receiving medical attention	20 million	

Nonreported injury and property damage (less than \$50/accident) costs \$3 billion (est).

The total injured, to the level of being medically attended, comes from the National Health Survey, reported by the National Safety Council,²⁶ but not included in their cost figures. Our estimate of 38 million people involved in accidents each year is astounding, yet in fair agreement with the National Safety Council listing for 1964 of 21,500,000 drivers involved in accidents,²⁶ since average car occupancy is 1.7. We guess at the 10 million with medical complaints, half of which are untreated.

This toll may be further summarized as follows: For every person killed with one vehicle involved, there will be 100 people injured to the level of receiving medical attention with 100 vehicles involved, and 400 vehicles reported to be involved in property damage of greater than \$50 without such injuries. The toll is now above 140 people killed every day, with the other values multiplied accordingly. For example, more than 70,000 motor vehicles are estimated to be reported in property damage or injury accidents every day. In National Safety Council estimation, two thirds of the \$9 billion direct costs of these accidents are due to the deaths and injuries (salaries lost, insurance and personal injury court settlements and overhead, and medical expenses), and one third of the direct cost is reported property damage. The National Safety Council cost estimates include only disabling injuries, but since this is mainly settlement and lost work cost and costs of medical treatment are only some 10% of this \$6 billion, or \$0.6 billion for 2 million severe injuries, the costs of the 3 million additional medically attended but not disabling injuries and 5 million additional medical complaint but not professionally treated injuries or shakings-up (the sore back, bloody nose, headache, black and blue spots, etc., on which many of us save money by not seeing a physician and save anguish with the police by not reporting) might add less than \$0.5 billion. If one were to include the property damages of all motor vehicle accidents, the total property damage would probably be above \$5 billion for a total direct cost of 1965 motor vehicle accidents estimated as above \$12 billion, rather than the \$9 billion based on National Safety Council methods of estimation. The indirect costs to the rest of us, delayed and anguished by the direct events, have not been estimated here.

There is still a considerable nonuniformity of accident reporting in the various states. With an advantage of avoiding penalties by not reporting accidents, including the penalty of loss of license to drive and hence loss of what has become in many cases an economic necessity with our inadequacies of public transportation, we should expect these values of accidents or injuries to death ratios to be low. How many children get black eyes or banged heads or even torn faces in single car accidents, who are not reported as automobile injuries, since this would only further hurt the family? Moynihan,²⁷ discussing this accident estimation problem, reports an Illinois study indicating that three quarters of the passenger car accidents involving 42% of the direct costs of these accidents, did not appear in official accident reports. Most of the unreported incidents were minor and not legally required to be reported. He suggests 40 million accidents in 1958 as an estimate rather than the 10 million

accidents estimated by the National Safety Council. If we define an accident as one involving property damage of more than \$50 or an injury involving need for medical treatment whether or not given, the order of magnitude of these ratios might more nearly be for each death, 125 injuries, and 500 vehicles involved in such accidents. More accurate statistics are needed to know the more accurate values. The divergence of these ratios of deaths, to injuries, to cars in accidents, from those ratios sometimes reported is a measure of the inadequacies or uncertainties of the data.

TABLE 6

Deaths to Injuries to Total Vehicles (or Drivers) in Accidents

	<u>Deaths</u>	<u>Injuries</u>	<u>No. of Vehicles (or drivers)</u>
National Safety Council ²⁶	1	36 (disabled)	450
National Health Survey ²⁶	1	94 (medical attendance)	
Our Estimate	1	125 (needing medical attention)	500 (more than \$50 damages or injury)
Solomon, ²⁸ 4 Lane Rural Roads	1	20 (reported)	53 (reported)
Dunham, ²⁹ Massachusetts (1953)	1	105 (injury reported)	400 (police reports plus more than \$100 damages or injury)

Since Solomon gives the average property damage for the rural vehicle accident involvements as \$320 (Table 6), it would appear that the reported accidents do not include many of the less expensive or less injurious events. Dunham's values are particularly interesting in their support of the higher injury ratio in a state with expectedly better accident reporting than many others. He indicates that five times the number killed are 25% or more disabled, not the three times used in Table 5. Prior to June 1953, only accidents with injury had to be reported in Massachusetts (see Twombly³⁰); thereafter, accidents with property damages over \$100 as well as those with injuries had to be reported. The total vehicles-in-accidents figure shown apparently includes police reports as well as Registry reports by drivers. The accident cost figures Dunham presents are 40% for injuries, 20% for property damage in injury accidents and 40% for property damage in noninjury accidents. These values do not agree with the National Safety Council values of 67% for injury and 33% for property damage costs, supporting the view that the National Safety Council values do not include costs of many accidents.

Note also Moynihan's emphasis²⁷ that the state and chronological variations of injury to death ratios may reflect more the availability of emergency medical treatment than any notable improvements in our transportation. Indeed, the new cars with the benefit of improved emergency treatment may be killing less but injuring many more, emphasizing the need for better statistics on the injuries.

With 5 million motor vehicles involved in medically attended injury accidents each year, and an average car life of 10 years, one can see that if the accidents were evenly spread, about half the cars made would be involved in injury accidents in the course of their use-life spans. Moynihan, Haddon, and Goddard²⁷ estimated (page 321 of the reference) that "something like one out of every four automobiles manufactured ends up with blood on it." As Moynihan puts it (page 302), ". . . the accident (is) the normal event--not normal in the course of a day's driving, but normal in the course of a vehicle's use span. Most automobiles are sooner or later involved in an accident in which a passenger is killed or injured by being smashed against the surface of the vehicle interior. There would almost certainly be an increase in the rate of safety innovations were vehicles designed in the context of this assumable accident future."

Similarly with pedestrians, it has been estimated³¹ that one car in 25 injures or kills a pedestrian within its use-life. This would seem warrant enough to design cars for this pedestrian impact event,^{32, 33} or indeed to make it an offense against society not to so design them.

The magnitude of this offense, this killing and maiming much of which we know how to avoid, is staggering. Between 1899 and 1936, motor vehicles killed 0.5 million people. Between 1937 and mid-1952, another half million were killed, and between mid-1952 and mid-1965 the toll reached 1.5 million killed, and will apparently reach two million by 1973. When one multiplies by 125 to count the injured, one counts most of us. It is probable that all of us will be injured in automobiles¹⁵ if we live out otherwise normal lives, and the chances through a life span are something like one in forty that we will be killed by these beautiful transportation devices.¹⁵ Automobiles are the major cause of death from age five to age twenty-nine.

With one fatal accident in something like 500, one can see then that something like 99.8% of the automobile accidents are survived. Paul,³⁴ examining Indiana fatal accidents in the early 1950's, reported that 43% of those killed were in "survivable" situations, 24% were in uncertain situations and 33% were in nonsurvivable situations, with destruction of the passenger area. This survivability figure would expectedly vary with speed. Thus, Moore³⁵ found that 95% of the car occupants had moderate to no injuries in dangerous or fatal injury accidents with impact speeds below 40 mph, and 60% still escaped with only moderate or no injuries with impact speeds above 80 mph. Moore summarizes his finding by stating, "Apparently the injuries occurring in lower speed ranges are largely a function of car design, while injuries in the higher speed ranges are a function of both speed and automotive design. Thus, the path for correction is shown by the basic indications of the data: Speed affects dangerous or fatal injury in a relatively small proportion of the cars; design engineering affects this grade of injury in all of the cars and in all of the speed ranges. Efforts to reduce dangerous or fatal injuries in automobile accidents must take

both these factors into account Control of excessive speed without simultaneous control of car design imposes limitations on the extent of reduction of dangerous or fatal injuries in injury-producing automobile accidents."

Huelke and Gikas³⁶ examined 79 car fatalities in Michigan. They felt that 34% would have been saved by lap belts, 11% more saved with lap belt and shoulder harness, 8% were undeterminable, and 47% were in unsurvivable situations. Note that lap belts alone are not enough protection; the need is for upper body support as well. Grime³⁷ concludes that seat belts (with the diagonal shoulder strap) can prevent about two-thirds of the severe injuries which would otherwise occur in Great Britain. Ryan³⁸ also concludes that safe auto interior design could cut the fatalities in half; his improvements of hydraulic bumpers and preloaded restraints could go even further. Dunham,²⁹ from Massachusetts data, shows that 41% of the people could survive in fatal injury accidents. He does not discuss the "unsurvivable" accident category.

Our analysis¹⁵ for the 1965 Stapp Conference of accelerations accompanying auto fatalities provides a preliminary indication that half of the automobile fatalities are occurring with a passenger compartment deceleration of less than 20G. Passenger compartments do not become unsurvivable in front end collisions--and then typically only in part--until passenger compartment loads exceed perhaps 45G; perhaps this number should be 60G, a value which the automobile industry would be helpful to provide. But this value is less for side and roof loads, or locally transmitted loads such as those to a rigid steering column or from a raised post or truck tail, a matter of growing concern. We feel that lap belts and shoulder straps, and seats which do not fail to over 30G could, if used, cut the car passenger fatalities to less than half. The human can survive 45G in decelerating from speed limits with little or no injury: our design limit for straps and seats should indeed be near this value, as Turnbow et al.¹⁹ recommend for aircraft. The airstop restraint, with automatic inflation of the chest airbag prior to impact, to provide protection without depending on passenger action of fastening straps and belts, would provide even better protection than chest belts or lap belts and shoulder straps.

As Severy and Mathewson³⁹ put it, "Since deceleration rates in excess of 40G have been voluntarily tolerated, the problem of avoiding injury from accidents with this degree of severity appears to be one of developing an adequate restraining device which will meet with the approval of the motoring public and which, of itself, will not cause injury." They³⁹ note, "For front-seat usage, the lap-type belt provides impact protection only for the less vulnerable portions of the anatomy, leaving the vital parts (head and upper torso) exposed to gross destructive deceleration." They found, "The chest-level safety belt is an effective means for restraining the body against the forces of impact which, in the absence of such a device, would result in the body being hurled against the forward surfaces of the car interior." This was written half a million car

deaths ago, perhaps half of whom would have lived if Severy's and Mathewson's advice had been followed. Indeed, three quarters of a million car deaths ago, very similar things were said about increased survival by improved restraints, and seats that don't fail, by DeHaven,⁴⁰ who also notes that in this period (1944) 70% of the urban car fatalities were attributed to accidents in which the speed did not exceed 30 mph.

The emphasis of this discussion is on vehicle and restraint problems after a crash. We are well aware that the human, except in suicide cases,⁴² does not voluntarily drive into accidents. Research must also be pursued in how to avoid crashes, by improvements in the road and environment and improvements in the driver as well as by improvements in the vehicle. Clearly, the driver must be given more selective control information and trained to be distracted less by the vast amounts of extraneous cues so that he can know how to drive to avoid crashes. Yet, 35% of those killed in fatal crashes in Michigan are in cars not at fault:³⁶ far too many of us are killed whether we drive well or not. Let us reduce the number of crashes, or at least by environment, driver, and vehicle improvements, reduce their severity, eliminating for a goal the very severe "nonsurvivable" accidents. Then let us make restraint improvements so that all will indeed survive the survivable accident. Our goal should not be just to cut the auto fatalities in half; we can do much better than that, with what we already know.

We note our concern for school bus accidents, now about 11,000 a year for the 200,000 buses driving 1.7 billion miles a year with 16 million students transported every day.²⁶ Some 4800 people are injured (disabled beyond the day of the accident) and 90 killed--including 15 students in the buses. This toll will grow as our schools further consolidate. Haven't all of you shuddered when you were passed on an expressway at 60 mph by a school bus loaded with students--unrestrained and in fragile seats?⁴¹ Our view is that restraints should be added, and that school buses should not be on expressways at 60 mph. On urban roads at slower speeds, the chance of an accident may be higher, but the chance of mass fatalities is lower. The current work of the University of California Institute of Traffic and Transportation Engineering on school bus restraints, to include the airstop restraint, is of considerable interest.

F. TRAIN ACCIDENTS

Although the train is now the safest mode of public transportation (Table 1), this was not always the case. Indeed, public indignation growing some hundred years ago over the slaughter, and railroad company neglect of safety, finally led to Federal laws, for air brakes in 1893 for example, regulating railroad safety. No similar laws yet regulate the automobile. Wooden bridges, wooden cars, poor brakes, coal stoves in each car ready to warm things up before and especially after a crash and poor communications all contributed to the number

of crashes or to the number of deaths and injuries following a crash. Yet solutions were proposed years before they were adopted or legislated. And "progress" pushed on. As Beebe and Clegg⁴³ put it, ". . . . as car construction became more substantial, the risks to which the cars were subjected were materially increased and as safety devices were perfected, the speeds at which passenger trains operated were accelerated. The grim reaper has never been altogether outdistanced by progress." As recently as 1943, 271 train passengers were killed in one year.²⁶

Present day trains even in crashes are remarkably safe, for the strength and weight of the cars ensure that the passenger compartment in a crash is rarely collapsed, and deceleration, except in head-on both-moving wrecks, is quite low. One of us (Clark) was in a train wreck in 1956, in Odenton, Maryland, with the car, following another and dragging another, going down a 5-ft embankment at 70 mph and ending up on its side. However, deceleration was moderate; no one in this car was apparently injured by the crash. The seven or so who died in the other cars all had part or all of their bodies out of windows in the course of the crash--with most of them in the car behind which hit a light post and so had significant lateral acceleration. The strong shell and generally low deceleration minimize deaths, but with no restraint against the "second collisions" of the passengers against car interior structures, injuries remain significant. Although only 13 passengers were killed in trains in 1963, and 2267 were killed in all "railroad accidents," 2135 passengers and 27,329 total persons were injured, for a passenger disabling injury to death ratio of 165.

Now we are ready again for train progress with plans for 150-mph trains on present roadbeds and over 200-mph (and some talk of 400 mph) trains on special roadbeds (or overhead tracks or tunnels). Work is to begin first in the "North-east Corridor" of Boston to Washington. These trains will be of lighter construction.

Such higher speed and lighter construction do not mean that we must accept a higher death or injury rate. Present engineering techniques allow us to define in advance and test to ensure an acceptable vehicle reliability, providing redundant systems for emergency alternatives to protect lives if the primary design system fails. Consider 500 or more people in a train traveling at 200 mph. Can we say that we will have a reliability such that this train will "never" hit another train or leave the track (i.e., with all such trains killing no more than 13 passengers per year)? To attain the required chance of survival, we will probably need a chance of survival even if the train is in a crash, just as we give our astronauts a means of escaping from their exploding space rockets. We should examine retrorockets for the emergency deceleration of the train. Likewise, we must consider restraints to protect us in a crash event. Yet, we do not want to huddle in tight astronaut restraints throughout our trip. We want to walk freely about. How, then, but by suddenly inflated airbags, can we grab all the passengers when an emergency develops and give them adequate restraint through a crash? We suggest that the airstop restraint and airbags inflating in the aisles and about the luggage have a definite place in high speed trains.

II. BACKGROUND

A. OTHER RESTRAINTS AND THE ORIGIN OF OUR AIRBAG RESTRAINT CONCEPT

The first use of belts for restraint during transportation is probably lost in antiquity, with the mother's binding her baby with thongs to her back. We were interested to see a cloth covered metal "lap belt" in a child's carriage made in Bavaria in about 1725 and seen at the Marstall museum of the Nymphenburg Castle in Munich (Fig. 1). The need for restraint in aircraft was publicized by such events in 1911 as Astley's switching on his engine in a dive--to be thrown out of his seat (he caught a wire and was able to crawl back into his seat and regain control), Reynolds' being thrown onto the upper wing when his aircraft was inverted by a gust of wind (where he remained (and survived) as his craft side-slipped to a crash) and Moisant's being thrown out of his seat by centrifugal forces, to be killed in view of thousands of spectators when apparently he abruptly steepened an already steep dive.⁴⁴

Lap belts gradually came into use. Figure 2 is of interest, showing Glenn Martin with a rudimentary shoulder strap, in April 1912, in connection with his newspaper delivery demonstration, as he tried to popularize aviation and show its practical applications--and raise money to build aircraft beyond this first one built in 1909 with its anterior primarily horizontal stabilizer and its bamboo struts and his second aircraft built in 1911.

Figure 3 shows an alternate 1912 approach of padding the passenger⁴⁵ with this "Aviation Protector" so that he (she) could be "thrown clear" of the aircraft in a crash, yet be protected.

It was young Adolphe Pégoud who, as far as we know, made the first adequate consideration of shoulder straps (Fig. 4) prior to his flying upside down and looping a Blériot monoplane in 1913.⁴⁶ During the summer of 1913, Pégoud spent hours in his airplane upside down on trestles, improving his restraint and practicing his control maneuvers under $-1G_z$ conditions, perhaps the first practical flight acceleration simulation test. (Earlier flight acceleration simulations were carried out by A. P. Thurston,⁴⁷ engineer for Hiram Maxim, in connection with the development of Maxim's "turnabout" flying machines restrained by radial wires, developed for the London Crystal Palace in 1903 to raise money for Maxim's aircraft developments. Thurston reached 6.5G and was thrown to the floor unconscious, perhaps the first human to be made unconscious by acceleration. But this was not flight simulation of any aircraft then able to make such flight maneuvers. Indeed aircraft dogfight maneuver loads⁴⁴ were generally less than $4G_z$ into 1918.)

Figure 5 shows the cockpit and 4-in. wide lap belt and no shoulder straps of the Martin MB-2 bomber in the early 1920's. Shoulder straps (with the lap belt) were

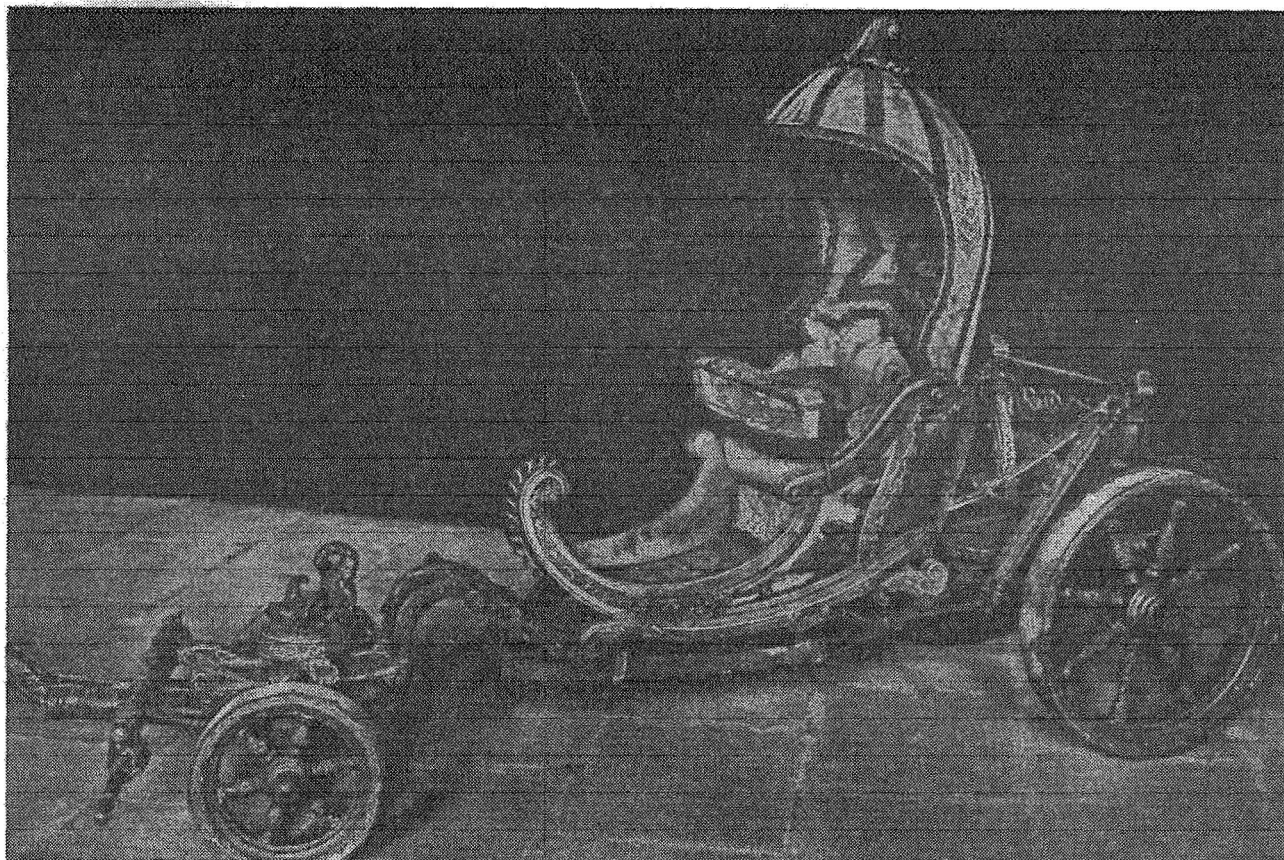


Fig. 1. Child's 1725 Carriage, with Cloth Covered Metal "Lap Belt"
(Marstallmuseum, Nymphenburg Castle, Munich)

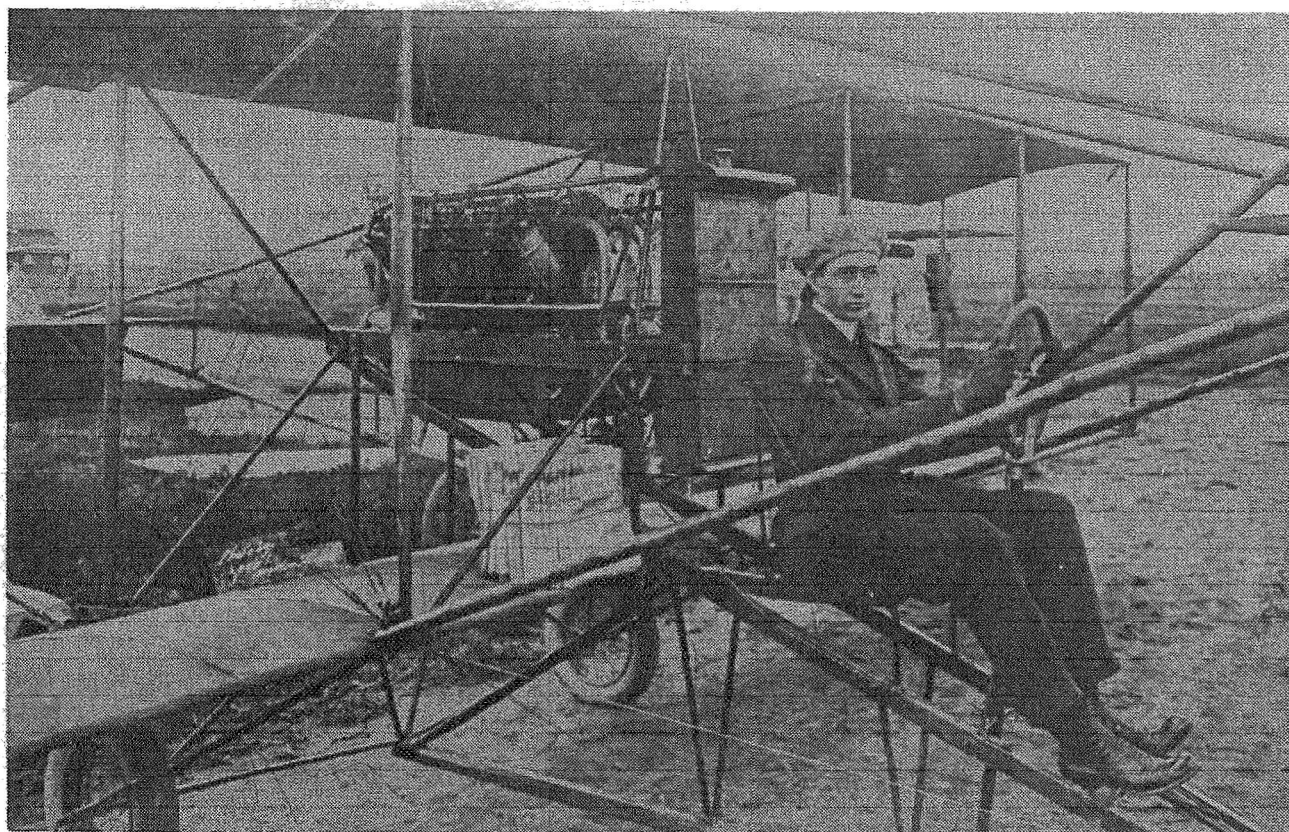


Fig. 2. Glenn L. Martin, April 1912, in His 1909 Airplane, with Shoulder
Straps Connected to the Lateral Control Yoke



Fig. 3. A 1912 "Aviator Protector" (Ref. 45)



Fig. 4. Adolphe Pegoud, 1913, with Shoulder Straps (Ref. 46)

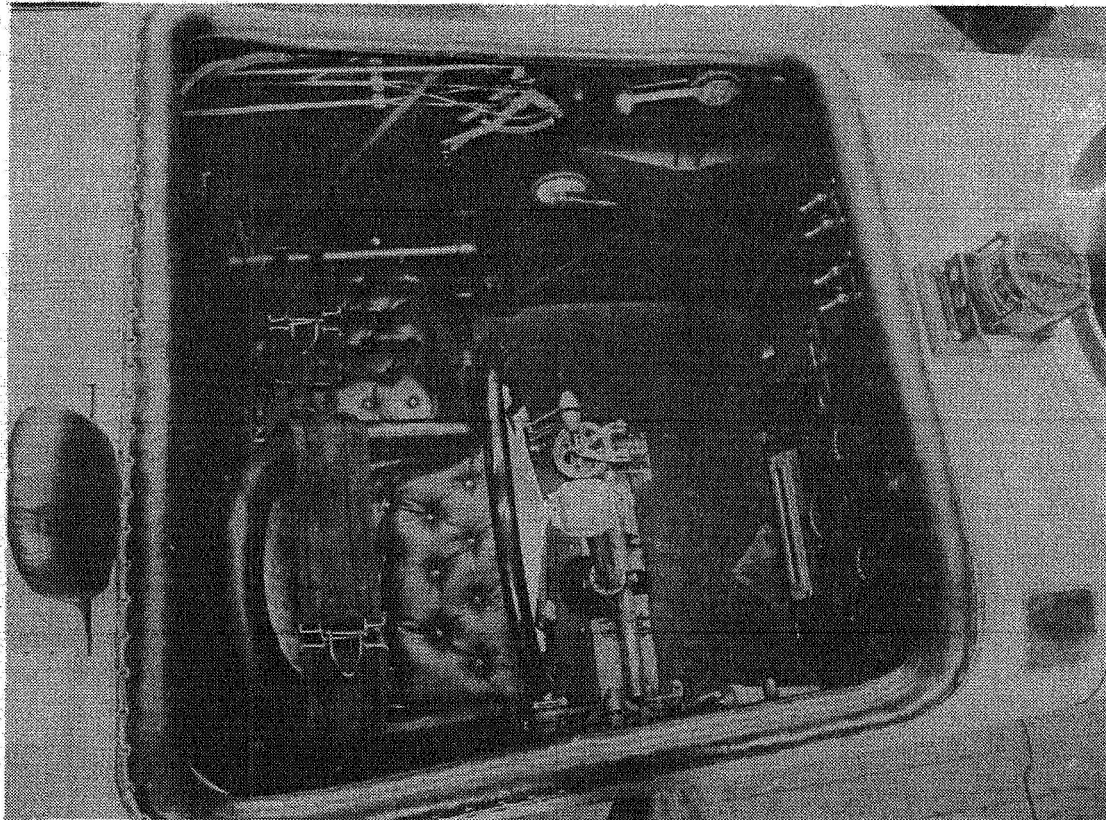


Fig. 5. Martin MB-2 Bomber (about 1920) with Lap Belt

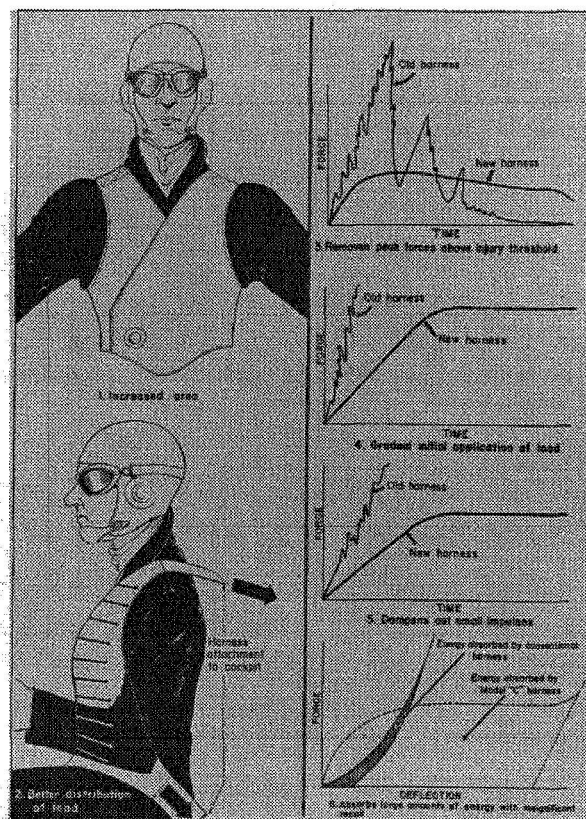


Fig. 6. Bierman's 1946 Broad Vest Restraint with Stretching Strap (Ref. 48)

probably not in general use even in U.S. military aircraft until the late 1930's. (We should and hope to look further into early restraint history.)

Following World War II, attempts were made to find improved restraints. Bierman⁴⁸ and co-workers particularly emphasized the advantages of a broad vest restraint for better load distribution with straps made of undrawn nylon, whose stretching characteristics provide load isolation from high onset rate and short duration acceleration peaks. Their experiments involved snap loading of the restraint on humans and dummies by arresting falling weights. The advantages of controlled yielding of the restraint were made clear (Fig. 6).

However, the basic human tolerances to impact acceleration, whatever the source, were inadequately known. DeHaven⁴⁹ had indicated humans might survive even 200G impacts. The classical work of Stapp⁵⁰ and co-workers, and followers, reviewed by Eiband,⁵¹ and by a symposium,⁵² showed that a well restrained human could indeed tolerate without injury $-45G_x$ attained at 500G/sec or less in decelerating from about 50 mph, and could tolerate $-45.4G_x$ in decelerating from 120 mph with only the reversible injuries of scleral and retinal venular petechiae. (The $-G_x$ acceleration terminology was developed by Clark et al.⁴⁴ to simplify reference to the implied direction of force on the body. $-G_x$ throws the heart forward in the chest, also called eyeballs out; $+G_z$ throws the heart down in the chest, and $+G_y$ throws the heart to the left.)

Figure 7 shows Col. Stapp and the restraint used in these 1951 tests, "forward-facing" with straps about the legs to prevent the lap belt from riding up onto the abdomen. Col. Stapp's work clearly showed that the weak link in crash survival was not the human, but his restraint and the integrity of his surroundings, just as DeHaven⁴⁰ had surmised. Indeed, it is interesting to find LeBailly⁵³ in 1922 calling for stronger airplanes so that they will not fail short of human tolerances. Figure 8 shows Clark in 1958 during the X-15 centrifuge simulation program⁵⁴ in a Navy flight suit incorporating an integrated harness with chest and leg straps as well as shoulder and hip straps, and with anti-blackout protection by inflating thigh and abdomen bladders. In this X-15 centrifuge program, we found the need for head support during the "re-entry" phase of the flight. At $-4G_x$, the pilot could not be sure of being able to hold his head up, particularly when this was combined with $+5G_z$ or more. The era of multidirectional acceleration problems in the newer flight vehicles had begun.

The Mercury Man-in-Space Program could have involved an emergency re-entry condition of the ballistic vehicle initially calculated to reach as high as 25G for a velocity change of some 1000G-seconds (including both the 18,000 mph

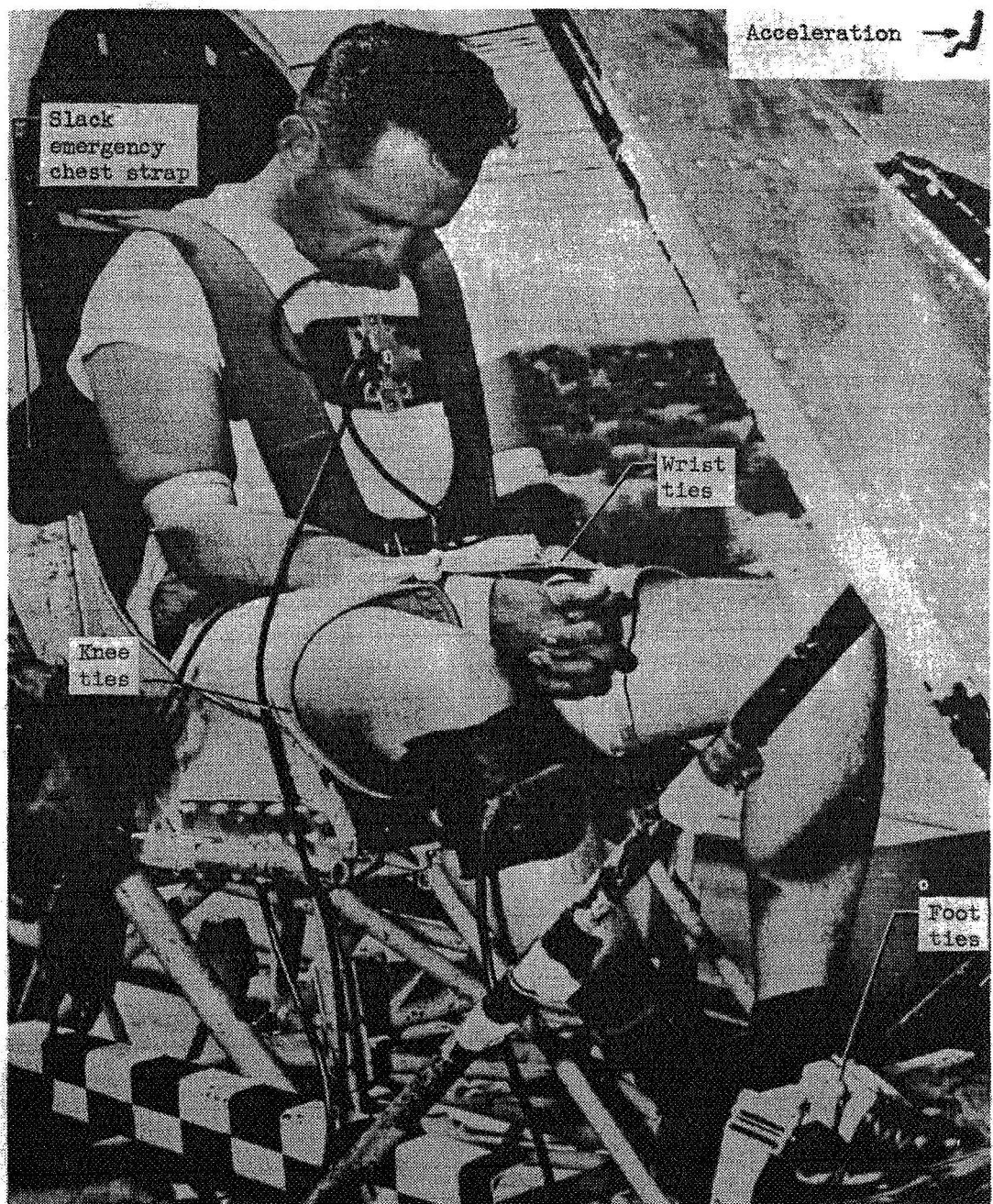


Fig. 7. Col. Stapp, May 23, 1951, Restrained for $-45G_x$ Including Thigh Straps (Ref. 51)

orbital velocity and the velocity equivalent of the 100 mile altitude potential energy), a condition never before experienced by man. Bühlén⁵⁵ had, however, shown tolerance of $17G_x$ over about 2000 G-seconds. With a contour couch (Fig. 9) conceived by Max Faget and developed and tested by NASA in cooperation with the Navy centrifuge laboratory, Carter Collins^{56, 57} indeed attained $25G_x$ on this broad support, limiting body distortion. In the actual manned Mercury flights of 1961 to 1963, only the normal re-entry accelerations of 7 to $8G_x$ were experienced.

For the Mercury condition of low altitude abort, also never experienced in manned flight but a condition for which the astronauts were trained on the centrifuge,⁵⁸ the escape rocket acceleration would throw one into the couch, then at burn-out, the air drag would abruptly throw one out of the couch. This condition was simulated by abruptly tumbling the centrifuge gondola inner gimbal through 180° after reaching peak G. For the one extreme run of this case at $11G_z$ (Fig. 10), the brief passage through $11G_z$ caused an involuntary arm tremor, attributed to brain hypoxia without unconsciousness. Figure 11 shows the broad upper torso, helmet, and arm restraints initially used for these tests, restraints further improved, with the addition of a chin and cheek restraint for experiencing $-G_x$ loads without discomfort, by Smedal et al.^{59, 60} For these accelerations in new directions and of greater magnitude and longer duration than the accelerations common with aircraft, new restraint concepts had to be examined, particularly those with broad support to minimize body distortion, which determines tolerance more than the acceleration value alone.⁶¹

As one examines crash conditions, decelerating from moderate velocities of perhaps up to 66 mph (3G-sec) in less than 0.2 sec, or particularly from the parachute descent velocities of early spacecraft of about 30 ft/sec, it is surmised that higher accelerations could be tolerated with broader supports than are provided by straps. Figure 12 shows the Chance-Vought rigid restraint system,⁶² with its broad body and leg supports to be preloaded just before impact. It is expected that this restraint would make deceleration from 30 ft/sec tolerable without injury at up to $-60G_x$, $-60G_y$, $+30G_z$ or $-20G_z$. Note that the goal of this restraint is to so rigidly support the human that he will experience precisely the deceleration of the vehicle without any of the dynamic overshoot effects commonly experienced with restraint straps, which without preloading may give the passenger deceleration of perhaps 1.5 to 2 times the deceleration of the vehicle.

But even such a broad surface support does not provide the truly continuous counter-pressure of water immersion, a restraint suggestion apparently first

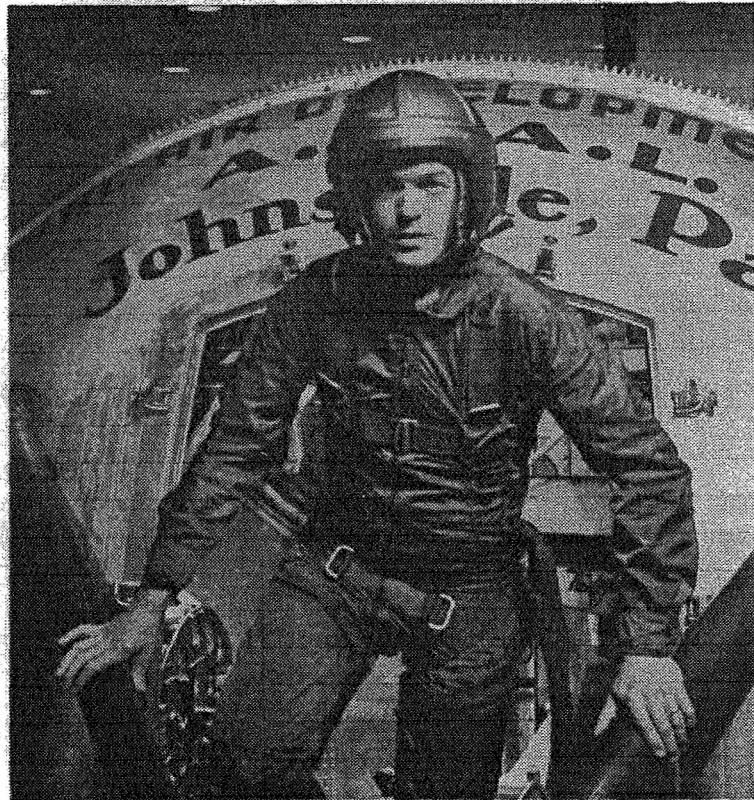


Fig. 8. Clark, 1958, in Navy Integrated Restraint, Including Built-in Thigh Straps and Chest Strap



Fig. 9. Couches for Project Mercury, NASA-AMAL Design on Left, NASA-McDonnell Design on Right

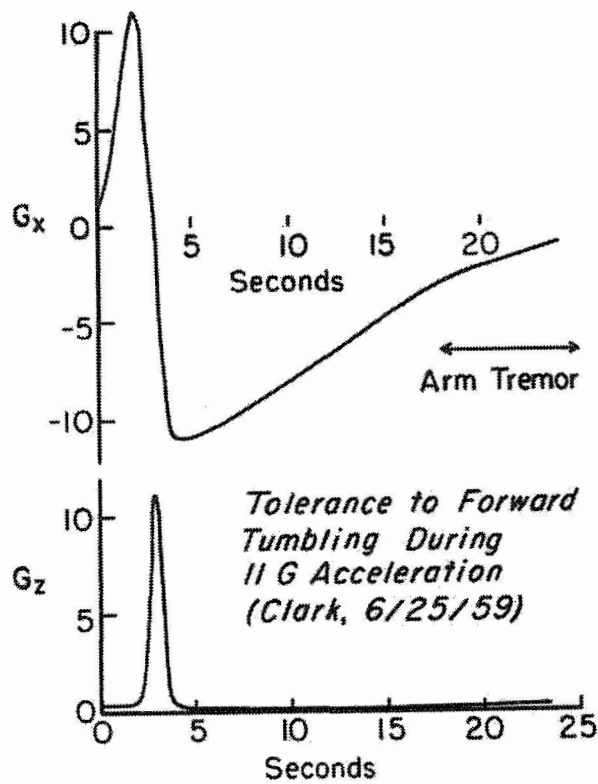


Fig. 10. Centrifuge Accelerations ("Tumble Runs") Best Simulating the Worst Case of Mercury Low Altitude Abort

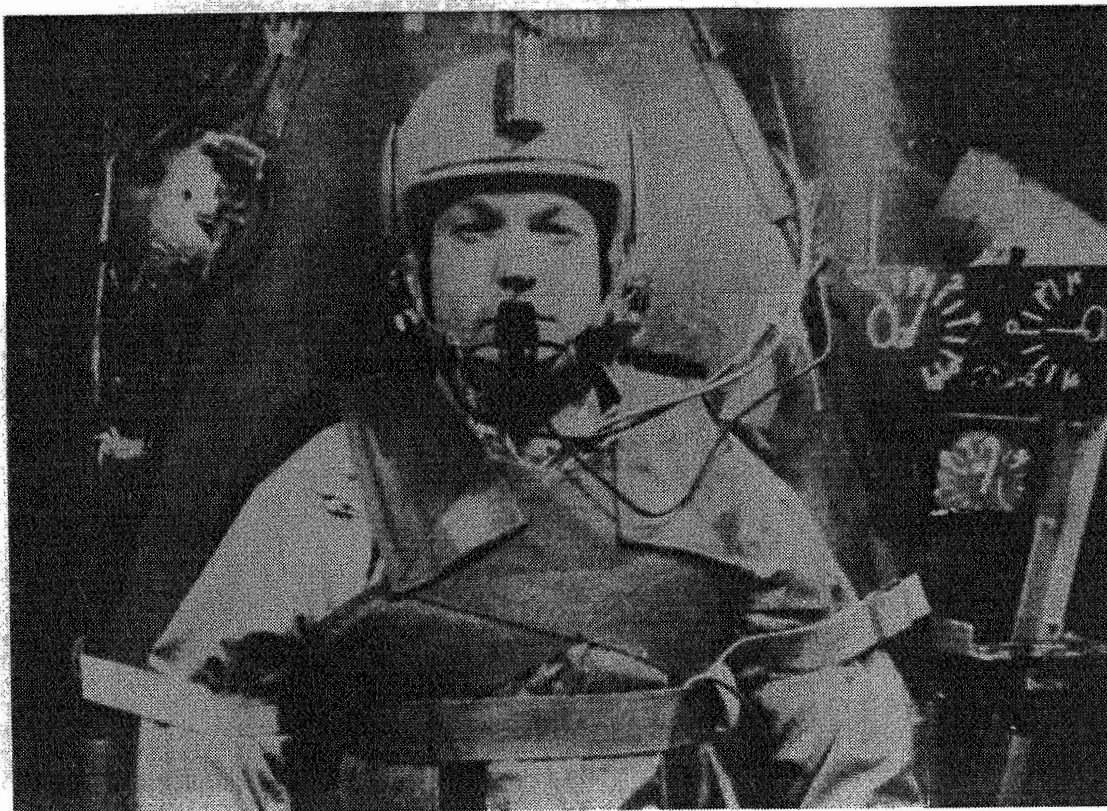


Fig. 11. Clark, June 1959, with the Broad Pectoral Girdle Strap Restraints for the Centrifuge "Tumble Runs"



Fig. 12. Chance-Vought Rigid
Restraint (Ref. 62)

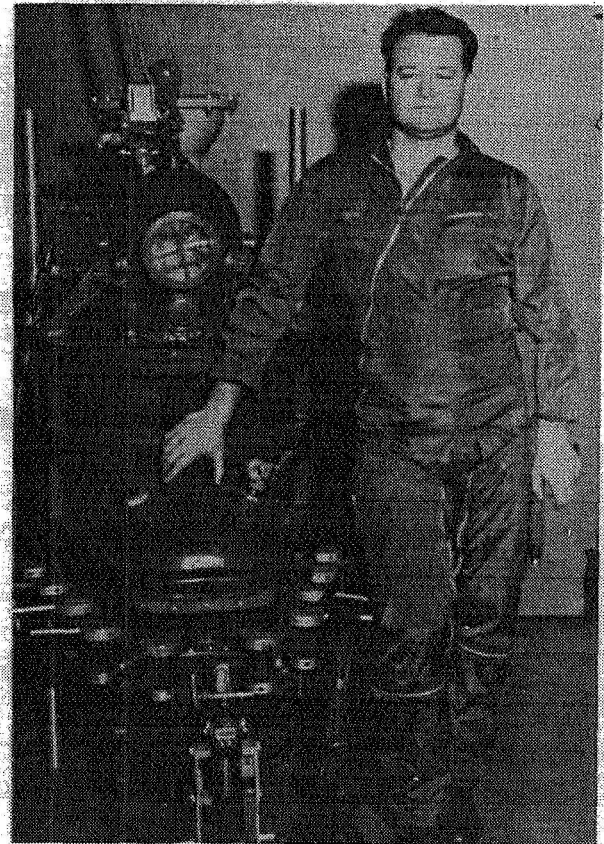


Fig. 13. Navy Water Immersion Restraint System
with R. F. Gray, Designer

made by Tsiolkovski.⁶¹ Figure 13 shows Flanagan Gray beside his "Iron Maiden" constant volume water restraint capsule, in which he attained $-31G_x$ held for 5 seconds, without injury. DeHaven⁴⁰ indeed suggested the possibilities of water protection for impacts of 100G.

These rigid restraint and water systems have the disadvantage of donning complexity or great weight. Clark and Gray in 1960 were interested in a broad surface support which could be light and rapidly applied in an emergency, and made a series of experiments with expanding polyurethane foam,^{61, 63} which indeed might be spraying into a vehicle prior to a crash. Figure 14 shows Clark in the first whole body foam restraint ("...in a ventilation garment, since the foaming reaction is highly exothermic--one thermocouple a few inches behind my neck read 267° F for awhile.") after the "escape" cutting wires broke and dissection by saw had commenced. The restraint seemed very effective. However, if there were a severe impact, a cavity would be opened up in the foam, reducing protection in subsequent impacts. Moreover, significant vibration isolation would expectedly not be provided by a foam stiff enough to provide adequate impact protection. A more ideal restraint would have its properties easily changed for the particular conditions.

Another approach to make a rigid restraint out of something light was developed by S. W. Shelton et al.,⁶⁴ using the limited distention-inflated "airmat" material (Fig. 15). Similarly, in the Vykukal-Ames restraint⁶⁵ (Fig. 16), an essentially rigid restraint yet one which could be carried about by the pilot, final tightening is affected by air bladders over the back and thighs. Clark rode the centrifuge in this restraint in 1960.

In April 1961, Clark joined the Martin Company, to find previous Martin work⁶⁶ (following earlier British work) with a "snatch-wire" airbag airplane landing system (Fig. 17), and the use of airbags to affect the first recover and reuse of an unmanned missile⁶⁷ (Fig. 18). These airbags had metal diaphragm blow-out valves to reduce rebound. Clark suggested an airbag restraint system for "universal" fit and some load isolation for the Apollo spacecraft, but this was not included in the final unsuccessful Martin bid. In an airbag restraint system under many circumstances, one can be isolated from at least part of the vehicle vibration or impact loads, not simply forced to tolerate the full vehicle loads as one would have to do in a rigid restraint system. In May 1962, response was made⁶⁸ to a NASA-Houston request for a proposal for a universal couch restraint system development. In this response, it was proposed that a "multiple gradient yield" acceleration restraint concept be examined using a series of low pressure and higher pressure-limited distension airbags as well as metal honeycomb (Fig. 19). In the couch design, broad anterior straps were suggested (Fig. 20). In addition, seated and full length capsule airbag restraint systems (Figs. 21 and 22) were proposed for study.

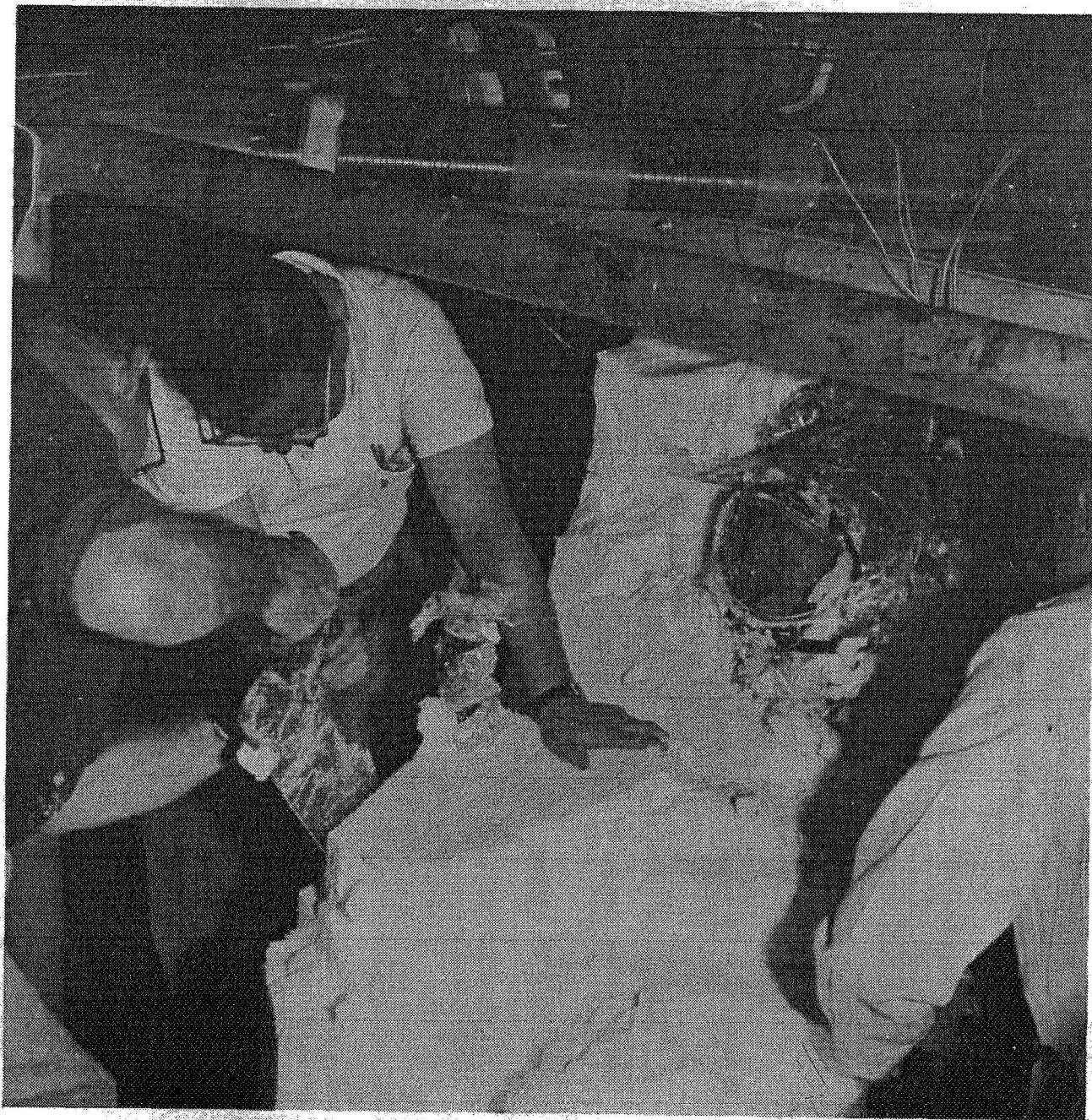


Fig. 14. Clark, 1961, in the Foam Restraint System



Fig. 15. Goodyear Limited Distention "Airmat" Restraint (Ref. 64)

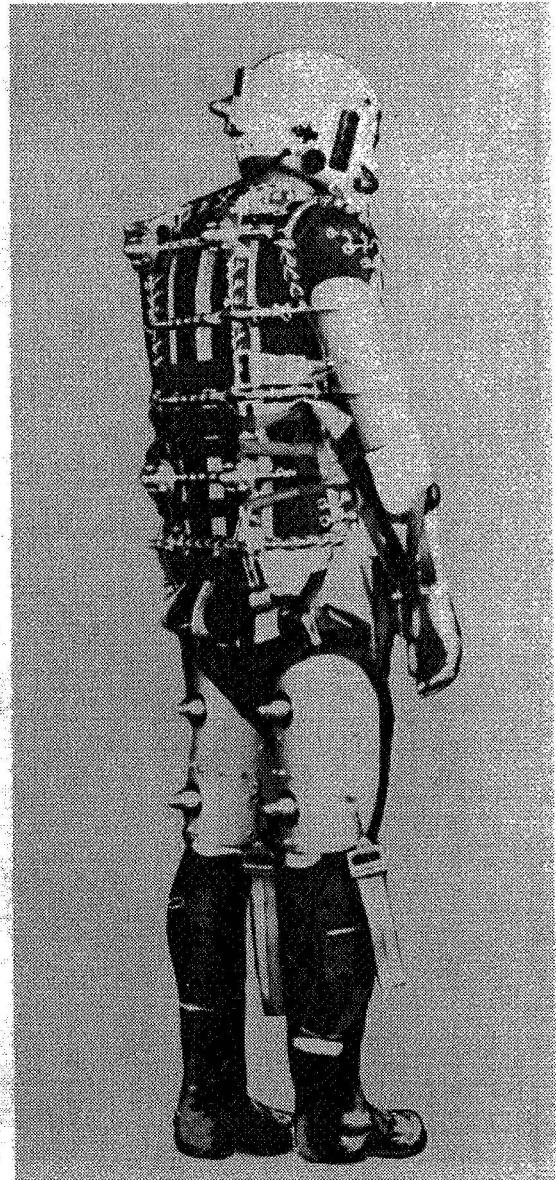


Fig. 16. Vykukal-Ames Restraint (Ref. 65)

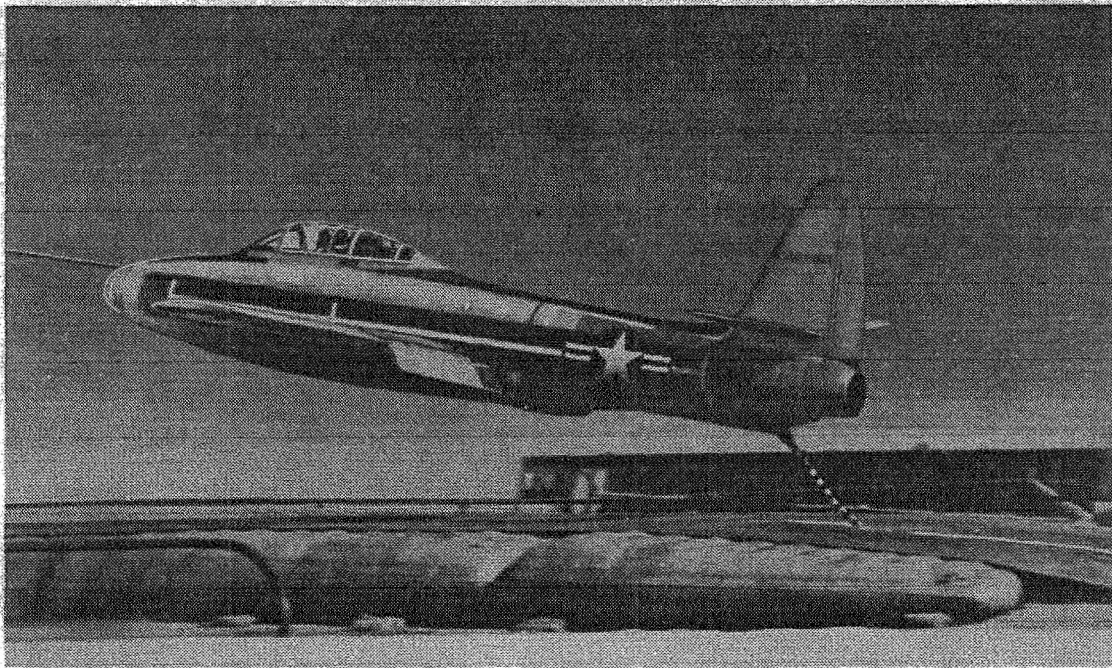


Fig. 17. Martin "Zelmal" Airbag Airplane Landing System

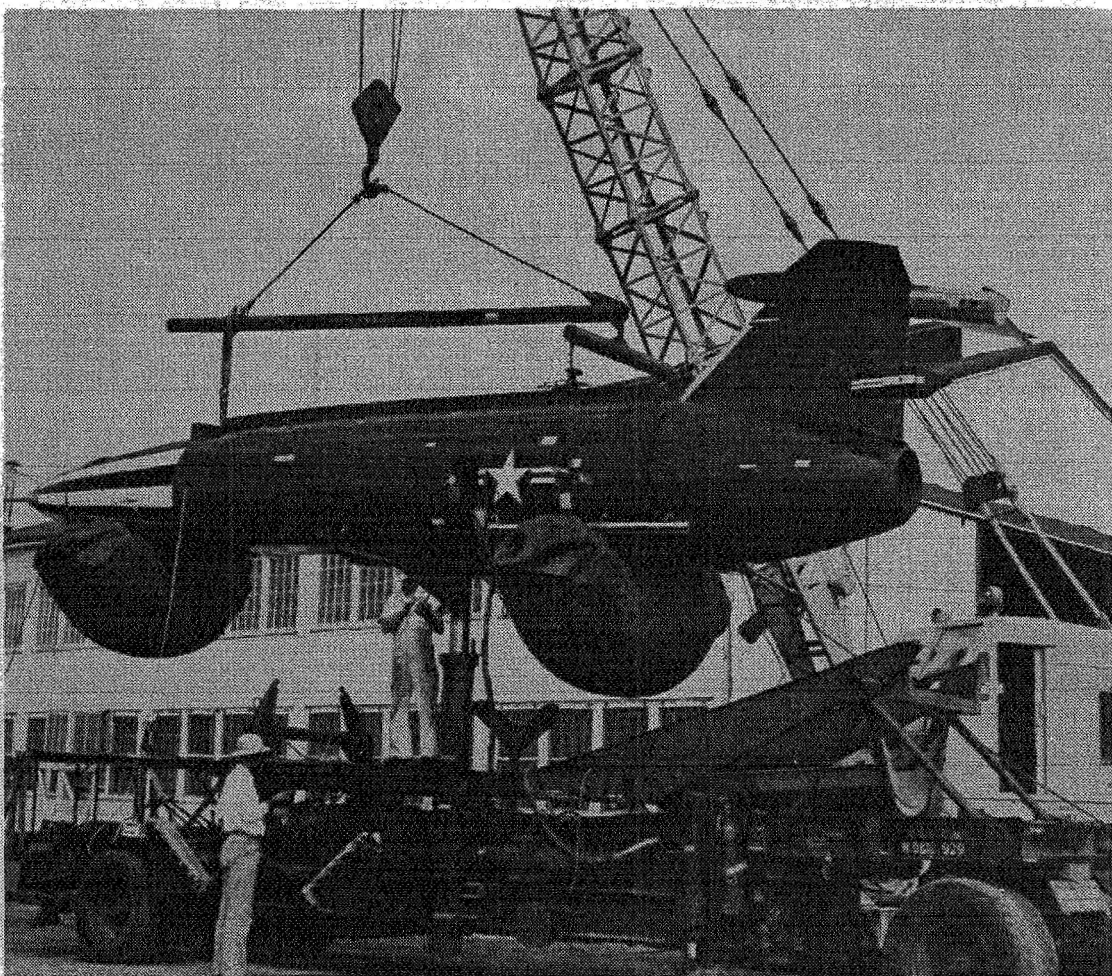


Fig. 18. Martin Matador Airbag Recovery System

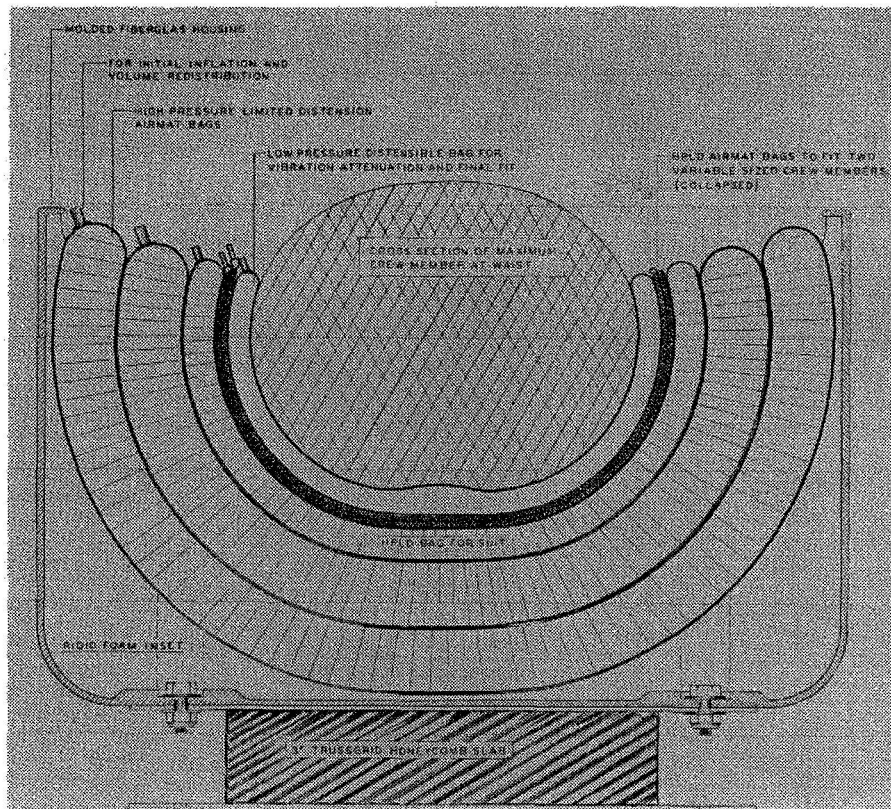


Fig. 19. Multiple Gradient Yield Acceleration Restraint Concept (Ref. 68)

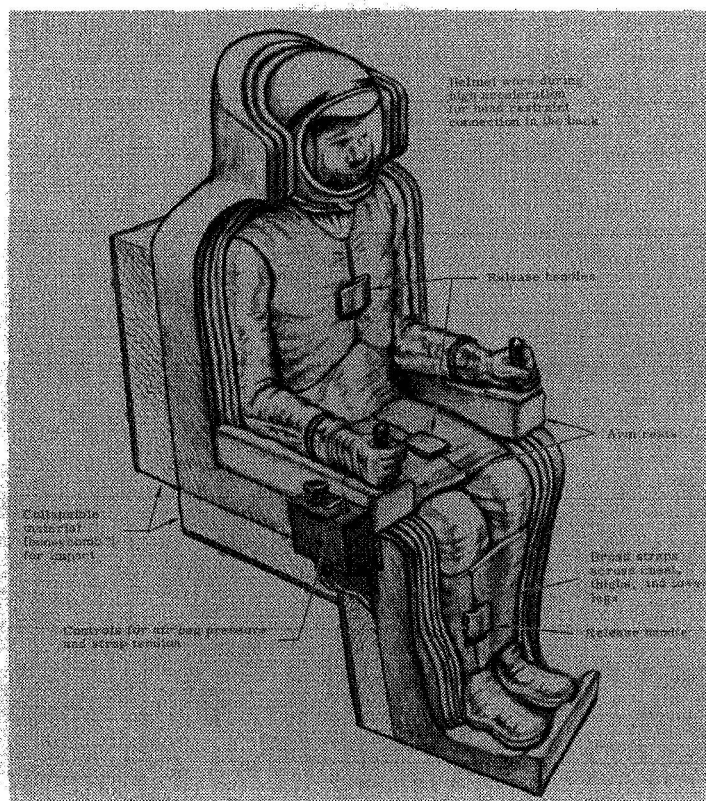


Fig. 20. An Airbag-Strap Restraint

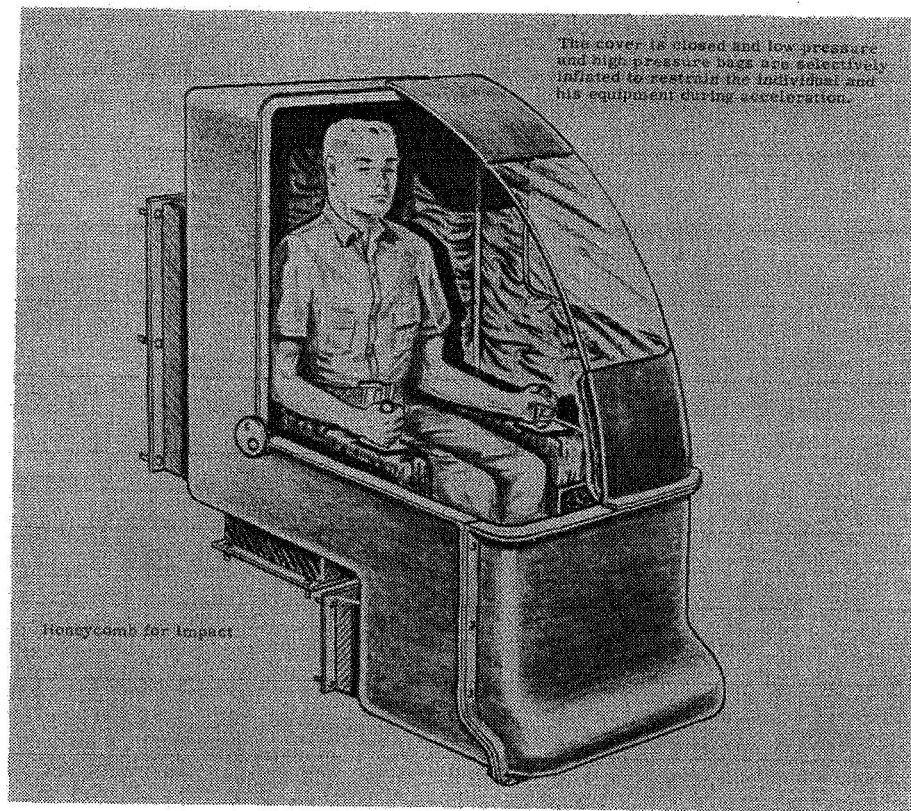


Fig. 21. An Airbag Seated Capsule Restraint (Ref. 68)

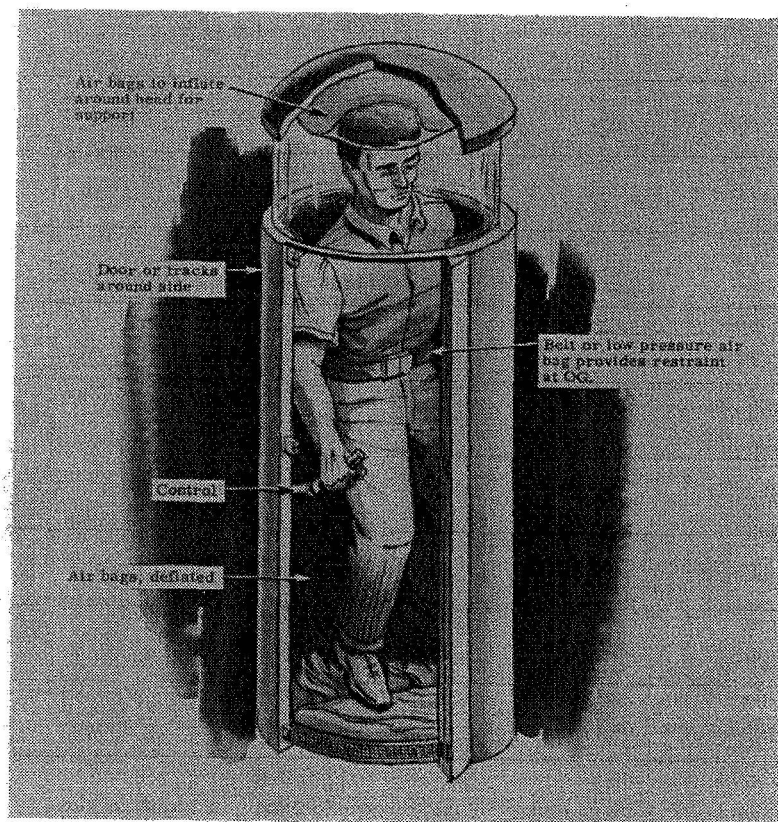


Fig. 22. An Airbag Full Length Capsule Restraint (Ref. 68)

This NASA couch restraint contract was lost, but customer interest in the problem led to authorization to carry out a Martin-supported research study on airbag restraints. In October 1962, after discussion by the authors, a commercial aircraft airbag restraint system was sketched by Carl Blechschmidt (Fig. 23) and later rendered by an artist (Fig. 24). As we began experiments in 1962, continuing to the present, we have come across increasing signs of the consideration by others of what we had considered as "our" airbag restraint designs.

B. OTHER AIRBAG RESTRAINT CONCEPTS

We have not found documentation of the rumored method of some aircrew members during World War II of inflating their life vests or life rafts just prior to a crash for crash protection. We have obtained a sketch, dated March 1952, from Assen Jordanoff showing a manually triggered airbag restraint system (Fig. 25), so that Jordanoff is apparently the first to systematically consider this restraint. Jordanoff made an airbag system in 1953 (Fig. 26), and described his concept in a demonstration and paper, "Passenger Crash Protection Device," at the 8th Annual International Air Safety Seminar of the Flight Safety Foundation at Palm Beach, Florida, in December 1956. This work was not published or patented although it was described in several newspapers and magazines of this period. We heard of it from Jerome Lederer, of the Flight Safety Foundation, in 1963, and subsequently have talked several times with Mr. Jordanoff, who has many ideas for further work on the system. In 1957, Jordanoff did some further work with the U.S. Rubber Company (Fig. 27), examining airbags made with Ensolite, a minimum rebound spongy material. Tests were made running into walls and corners.

U.S. Patent 2,649,311, filed on August 5, 1952 by John W. Hetrick and granted August 18, 1953, covers safety cushions for automotive vehicles, which are automatically inflated when there is a sudden slowing down of the vehicle. These cushions would be mounted on the steering wheel, glove compartment, instrument panel, back of the front seat, etc. We have not identified Hetrick's earlier work before filing his patent application, but his is the first patent we have found on airbag restraints.

H. A. Bertrand, in October 1955, filed an application for the U.S. Patent 2,834,606, granted May 13, 1958, for a safety device for passengers in a "conveyance" (Fig. 28). These "airbags" are filled by manual switch operation, with automatic deflation after a time delay. Bertrand's further Patent 2,834,609 offers refinements.

Proposed human restraints involving airbags, which we have found in the aerospace literature, include the "freedom-restraint" concept of Douglas,⁶⁹ with bags inflated around a lap shelf (Fig. 29), which Al Mayo apparently originated and says he did try in a crash simulation test,⁷⁰ and the "catapiller

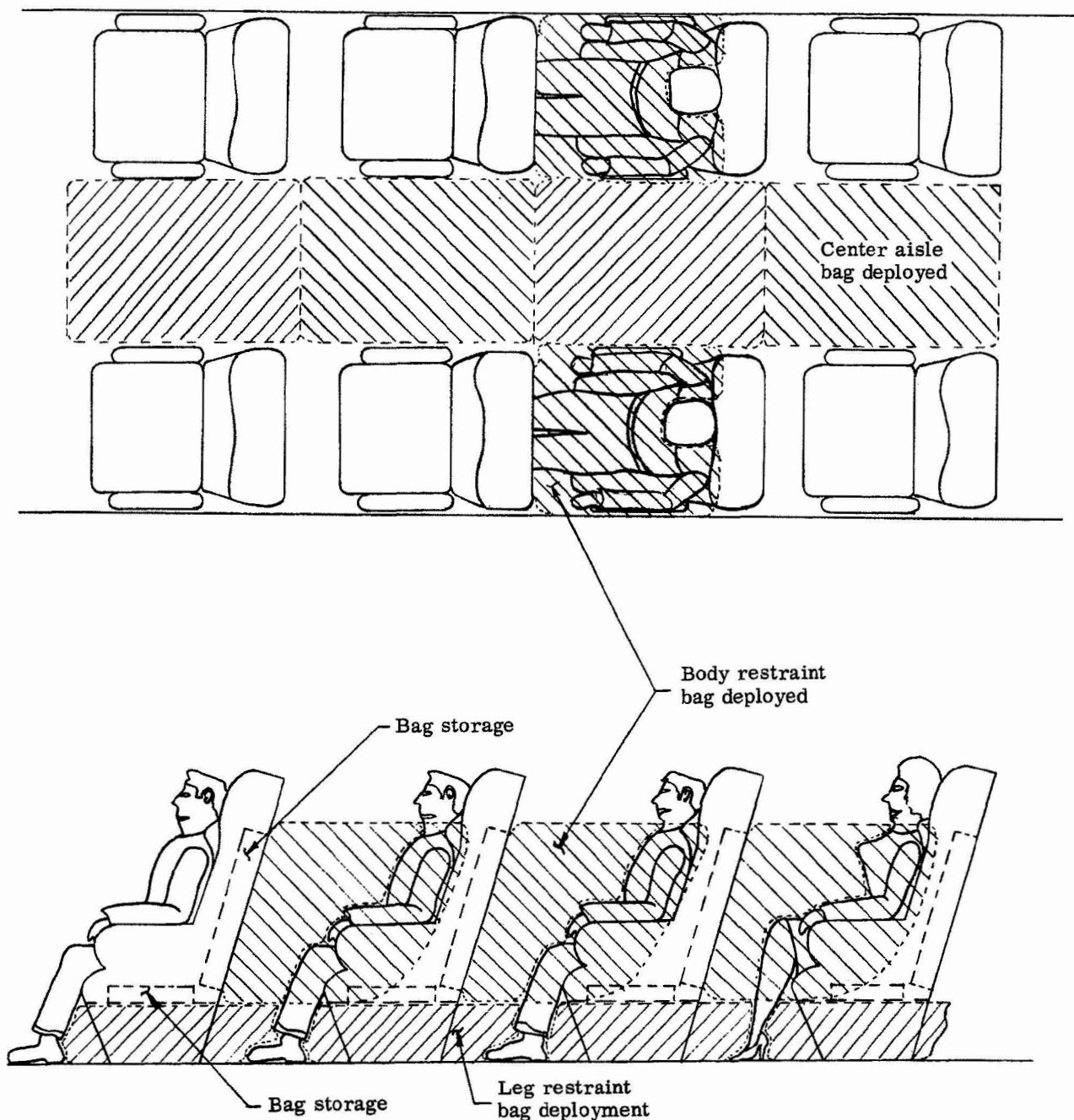


Fig. 23. Airbag Restraint for Aircraft Passengers, October 1962

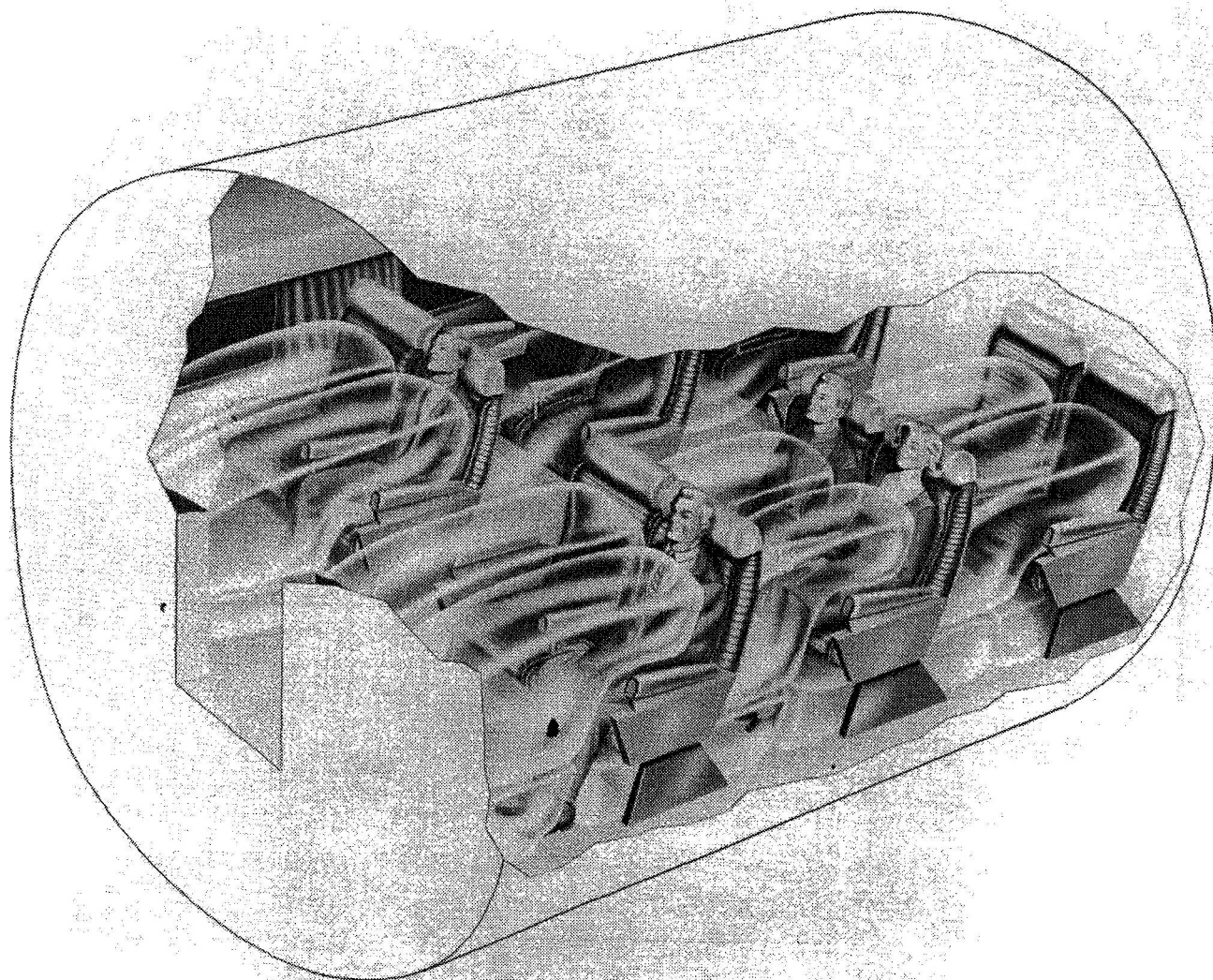


Fig. 24. Artist's Concept of an Airbag Restraint for Aircraft
(or Bus or Train) Passengers

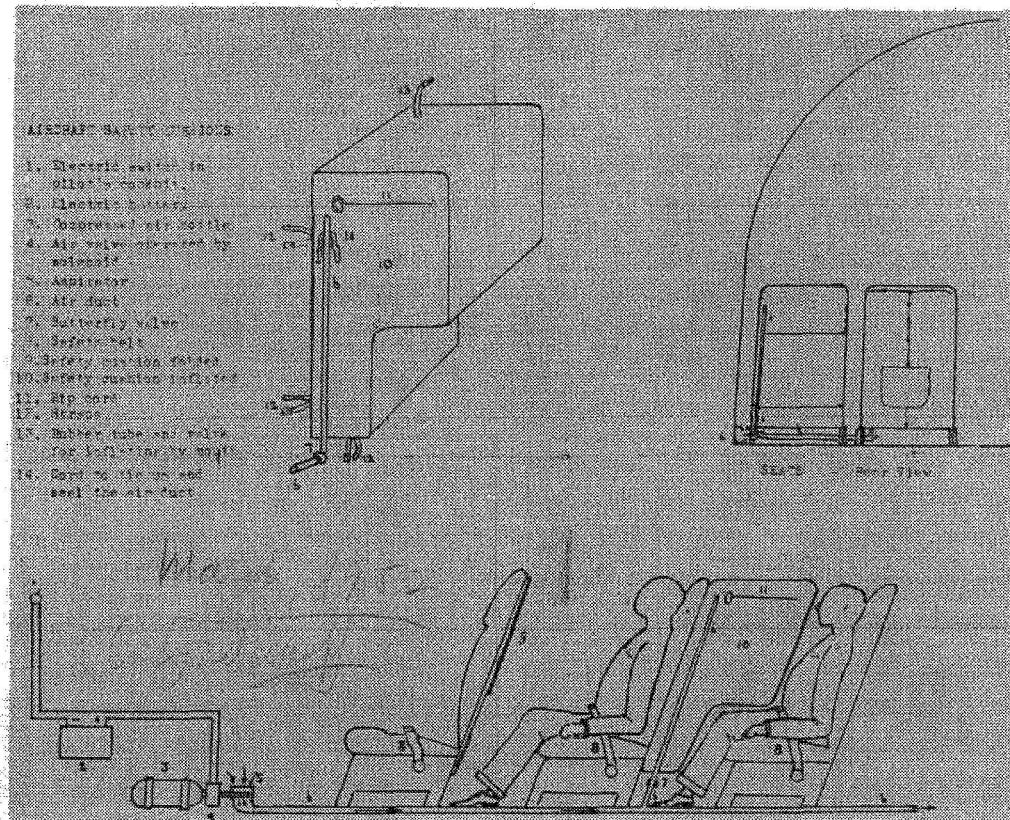


Fig. 25. March 1952 Jordanoff Airbag Restraint



Fig. 26. Jordanoff in 1953 with a Prototype Airbag Restraint

restraint" design of Ling-Temco-Vought,⁷¹ involving a series of inflatable fabric bags supported by semicircular metal formers in front of the body, which was considered and rejected for development. The Douglas "freedom-restraint" system with its lap shelf could not utilize the controlled displacement for load isolation of "our" system.

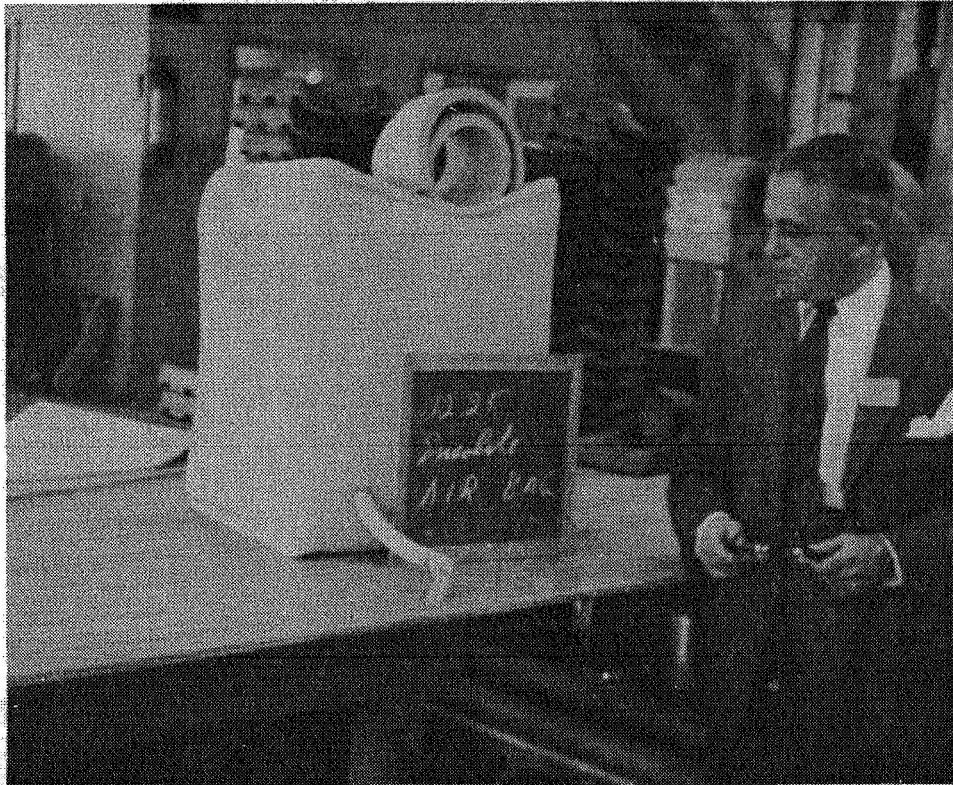


Fig. 27. Jordanoff in 1957 with an Ensolite Airbag Restraint

We received correspondence in April 1965, from Donald W. Benrud, of Goodhue, Minnesota, that he independently had the concept of airbag restraints for aircraft in the winter of 1960 to 61 fully documented and drawn up in April 1961 but not patented. He presented his idea of using plastic bags with elastic bands for automatic retraction to G. T. Schjeldahl, maker of many of the high altitude plastic balloons, but Schjeldahl decided not to pursue it. Benrud asked for an evaluation of his concept by the Aviation Crash Injury Research Group (Phoenix, Arizona) of the Flight Safety Foundation, and finally received a reply from Victor Rothe with many criticisms and no offer to run tests. We consider him one of the unsung pioneers in our common airbag restraint concept.

May 13, 1958

H. A. BERTRAND
SAFETY DEVICE FOR PASSENGERS

2,834,606

Filed Oct. 5, 1955

2 Sheets-Sheet 1

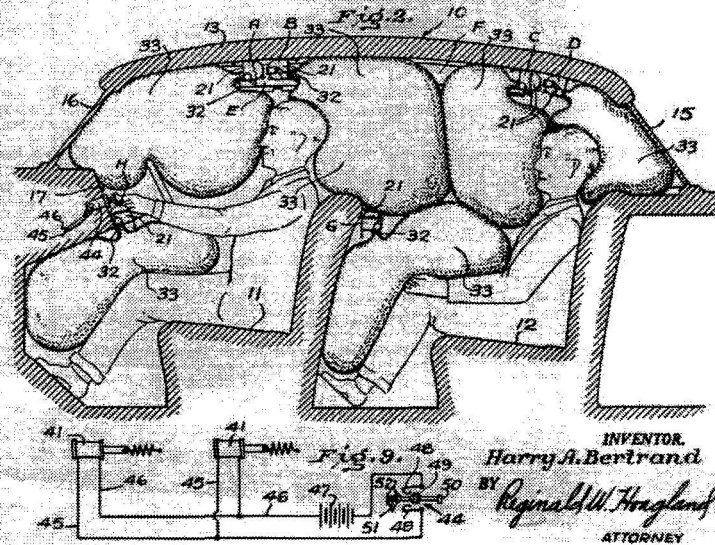
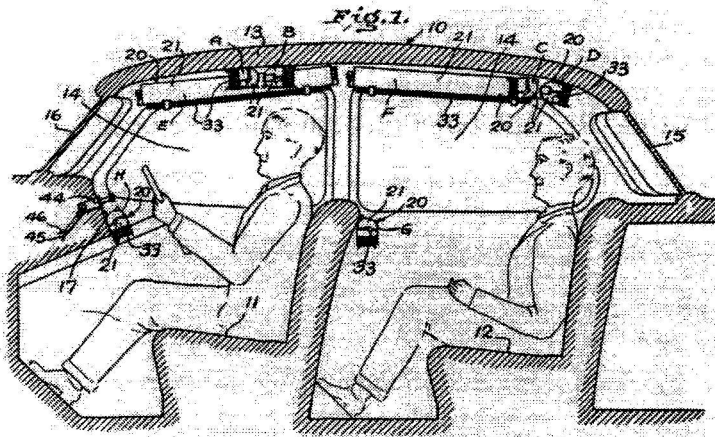
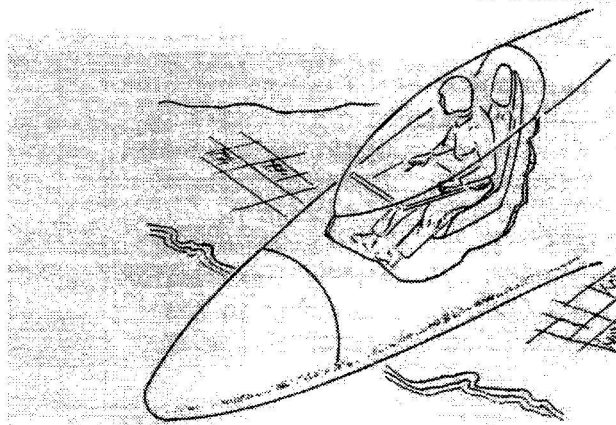
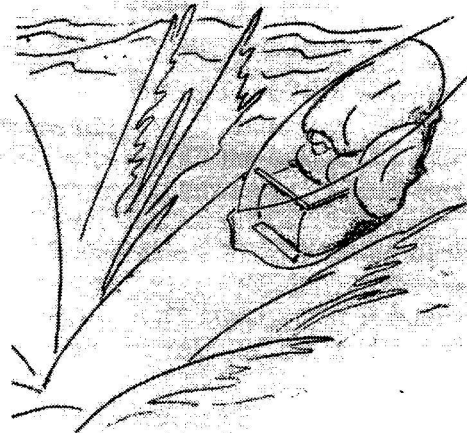


Fig. 28. Bertrand 1955 Airbag Restraint



Pilot unencumbered
in normal flight



Pilot completely
encased during crash

Fig. 29. Douglas (Al Mayo) Freedom-Restraint System (Ref. 69)

Subsequent to our airseat design work, the Martin Patent Office has located U.S. Patent 2,057,687, by Frank G. Manson, filed August 16, 1935 (thirty years ago!) and granted October 20, 1936, on a "pneumatic airplane seat." Manson says, "It is also readily apparent that when my form of chair is used in any vehicle, particularly an airplane, and one seat is immediately rearward of another, the forward seat will form a "crash pad" in case of an accident or forced landing." He continues, "It will also be seen that in the case of a sudden vertical descent of an airplane, especially where the plane suddenly contacts the ground vertically, there will be sufficient shock absorbing in my type of seat to eliminate any ill effects to the persons in the aircraft due to the impact shock." He states, "Another object of my invention is the construction of a chair for an aircraft in which the seat portion of the structure is readily and easily adjustable to different heights." This method of seat adjustment by selective bag inflation was further refined for horizontal and vertical adjustments by W. J. Flajole, U.S. Patent 2,938,570 filed July 5, 1957, and granted May 31, 1960, a possible method to allow the airseat base to be fixed to the automobile or aircraft.

It is clear from our experience in resurrecting patents on "our" safety concepts that a great many other safety ideas may have been previously presented (though often not in the technical literature). The needs of safety could be well served by digging out and applying the previous ideas: we don't have to wait for new revelation. As we put it, there's many an excuse between research and use. We should indeed, as the Committee on Highway Safety of the National Academy of Sciences Highway Research Board is just starting to explore, make an Inventory of Safety Concepts, from patents as well as from the literature. The government agencies should continually re-examine these concepts, and support their re-evaluation and development if new materials or techniques or needs make this desirable.

C. OUR INITIAL AIRBAG RESTRAINT RESEARCH

A Martin-sponsored airbag restraint research program was initiated in May 1962, with 168 manned vibration and impact tests subsequently carried out. For this first manned experimental program with airbag restraints (for the others with airbag restraint concepts had apparently at most done a test or two, apparently without measurements), a very simple system was used, consisting of full length latex rubber (32 sprayed layers) airbags above and below the body, closed in a reinforced wooden box 22 x 34 x 84 in. in size. The upper bag and box had a hole for breathing. Vibration tests were carried out with the box mounted on a C-25 Electrodynamic Shaker, with much of the box weight supported on a low resonance spring system (Fig. 30).

As would be expected, this restraint provided excellent vibration isolation for frequencies above approximately twice the body-bag resonance frequency of 3 cps: the man could stay still while the vehicle vibrated about him. For example, at 11 cps, the frequency of concern in the "Pogo" vibration⁷² of the Titan rocket

prior to its modification as the Gemini launch vehicle, in a moderately rigid restraint (astronaut couch), $1 \pm 3G_x$ vibration of the vehicle becomes intolerable in 15 seconds.⁷³ In the airbag restraint Clark rode $1 \pm 3G_x$ at 11 cps of the vehicle for 5 minutes, as the load on his hip was reduced to $1 \pm 0.4G_x$. Fortunately, it was possible by equipment changes⁷² to damp the propellant line pressure surges and hence the thrust surges and reduce the Gemini launch vehicle "Pogo" vibrations to below $\pm 0.25G_x$ so that changes in the couch restraint were not required. However, it is noted for future vehicles that vibration isolation by airbag restraint is an alternate solution.

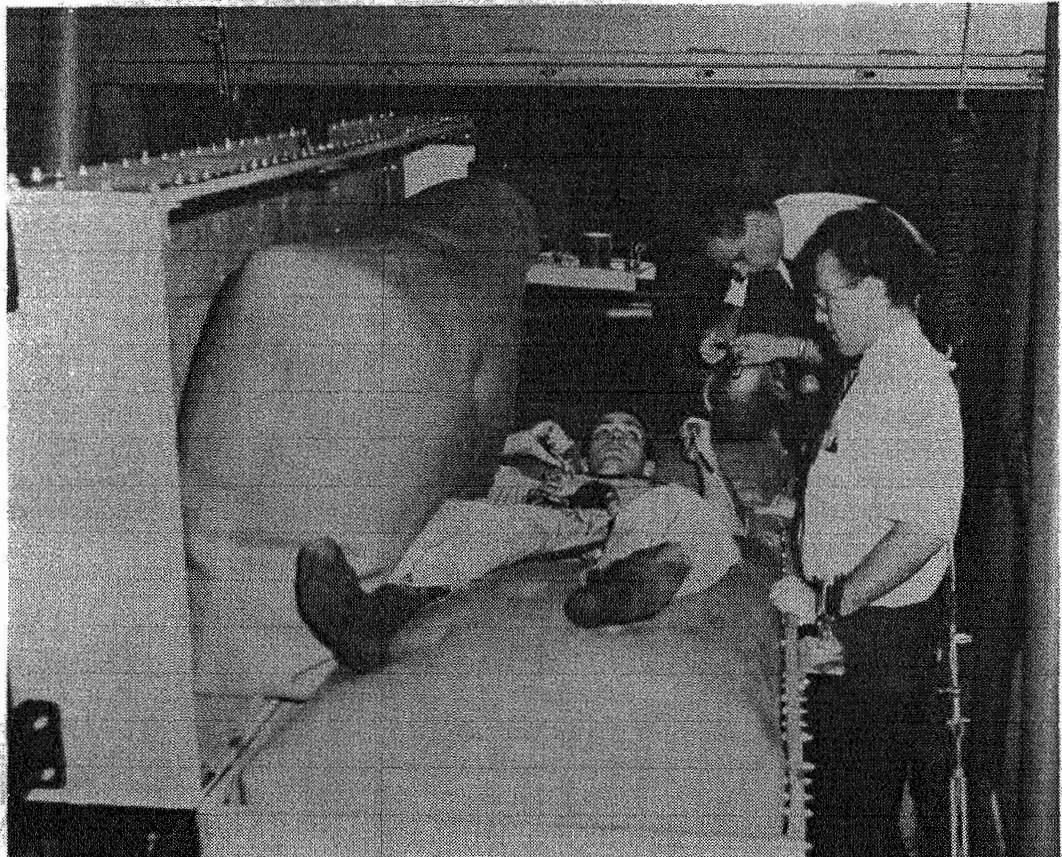


Fig. 30. The First Martin Airbag Restraint Experiment (1962)

For impact tests, the restraint box was hoisted above a smoothed sand box and dropped. The classical dread of elastic restraint systems is that they will increase the load by dynamic overshoot and rebound, or by "bottoming" through the restraint onto rigid surrounding structures. Airbag restraints have the advantage over most other restraints that their dynamic characteristics can be readily changed, particularly without discomfort when a subject is in a pressure suit, by pressure changes, to ensure a minimum dynamic overshoot for the

particular conditions, and no bottoming. We like to speak of airbags as "active" elastic restraint systems, whose properties can be changed for the particular conditions, as opposed to "passive" elastic restraint systems, such as a sponge cushion, whose properties cannot be changed. Fortunately, the low bag pressure of 10 in. of water above atmospheric pressure (i. e. , 0.3 psig), which was comfortable without a pressure suit, was sufficient to prevent bottoming even in this small box with only 7 in. of available travel, when body buckling was avoided by lying on a back board.

But rebound does occur in an airbag restraint system. If elasticity were perfect, the rebound velocity would equal the approach velocity, the velocity change (or G-seconds of acceleration time) would be double that of just stopping from the approach velocity in the first impact, and indeed the body would continue to rebound. This rebound problem has been of considerable concern to others, with consideration of means to abruptly drop air pressure by opening a valve or diaphragm at maximum pressure,⁶⁷ or bleeding gas from the bag during the pressure stroke,⁷⁴ for example. Others have felt that the airbag system could not dissipate the impact energy; it could simply store it up by bag pressurization and conversion to potential energy, to be followed if the high pressure gas is not vented by reconversion back to kinetic energy again (rebound), with the protection problem remaining if not indeed made worse by the supposed doubling of the velocity change.

We have found a little experimentation highly salutary to over-simplified and too often pompous theory. Rebound in an airbag restraint does occur--but not continuously and only for about three cycles (1 sec). Initially, we were also afraid of this rebound, and built our bags with small and then large valves (Fig. 31), but opening the valve deflates the restraint. If the vehicle hits a second time (as aircraft generally do), the passenger would be unprotected. Therefore, we made impacts without opening the valve, and found that since the rebound is at such a low frequency (3 cps) below most of the body resonances, and quickly over, it is not unpleasant. The vertical crash is experienced as a multiple pat of the restraint rather than the single slam of the rigid restraint system. We found that even without internal baffles in the bags, these motions into the first airbag restraints are at about 11% of critical damping. We conclude that human airbag restraints should not be vented during the impact, but only for egress after all motion of the vehicle has ceased.

The impacts were made at drop heights up to 5 ft. In this last drop, the average peak of three accelerometers on the box was $440G_x$; the load on Clark in the airbag restraint was $16.7G_x$. For higher approach velocities, the load isolation would not be this large, but clearly the use of controlled displacement into the restraint should be examined as a means of load isolation for landing spacecraft.

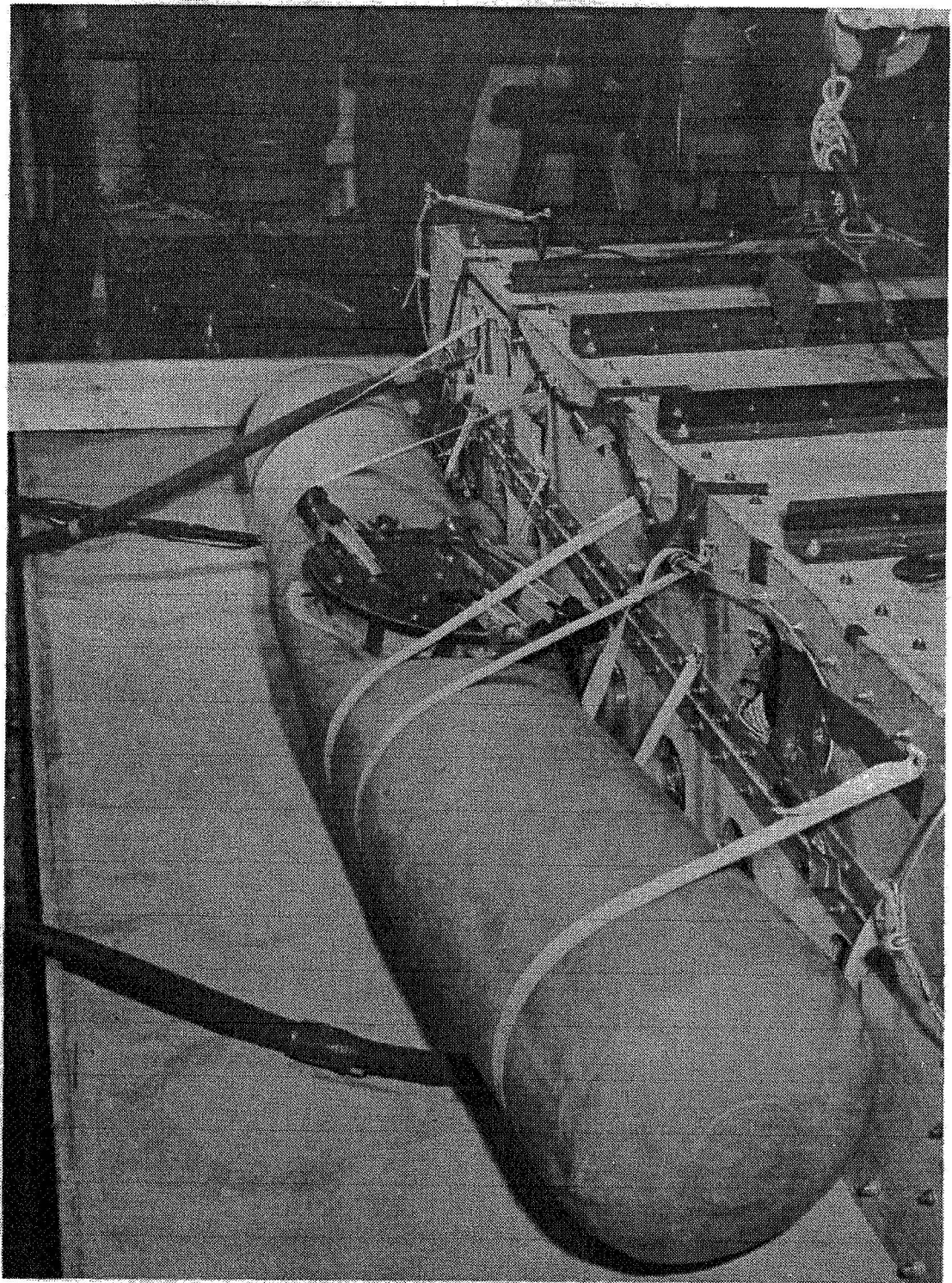


Fig. 31. Valve Used for Dumping Airbag Pressure, Found Unnecessary

With these results, the Office of Biotechnology (Dr. Eugene Konecni, Head) of the Office of Advanced Research and Technology, Headquarters, National Aeronautics and Space Administration, was approached in December 1962.⁷⁵ In January 1964, a contract (NASw-877) was signed with the Martin Company to examine a "Pilot Compartment Airbag Restraint System" for astronauts. We note that an airbag, with vent-ports, was used on water landing for impact load isolation of the entire Mercury spacecraft.⁷⁶ Whether or not such a system is used, restraints within the spacecraft are also required.

D. THE SPACE APPLICATIONS CONTRACT⁷⁷

In order to scale the airbag restraint up to a size commensurate with the crew area of a manned spacecraft, we selected a Mace section shipping container some 6 ft in diameter and 12 ft long, appropriately modified, as our simulated spacecraft (Fig. 32). The simulo-astronaut (Clark or Blechschmidt) lay in this vehicle on his back, within four airbags, above and below him and at his head and feet, with some 2.5 feet of allowed motion in any direction. The vehicle was hoisted up as high as 28 feet with a dummy subject and 16 feet with a human subject and dropped into a sand box; 45° feet down and 45° roll left drops were also made, with special runners added to the vehicle for strengthening. Figure 33 shows the 16 ft drop at 45° feet down, with an impact speed of 32 fps, a typical value for a spacecraft under a parachute. It is clear that considerable load isolation is provided, as well as good protection for multiple impacts.⁷⁷

We did not directly vibrate this vehicle. However, Fig. 34 shows the expected response to a $\pm 3G$, 11 cps vibration occurring to the vehicle during launch, computed on the characteristics of this larger airbag restraint system of 2.05 cps resonance frequency at 11% of critical damping. The load on the subject would be $\pm 0.15G$.⁷⁸ Note also that during the steady launch acceleration, the astronaut would sink into his restraint some 0.8 ft at 6G, if the bag pressure were not adjusted. By adjustment of lower bag pressure proportional to launch acceleration (and this could even be done manually), the astronaut could be held in his original position at the instrument panel.

We suggest the use of transparent elastic plastic bags for spacecraft (Figs. 35 and 36) and did some preliminary experiments with an elastomeric polyvinyl chloride bag made for us by the Lindron Corporation, Pawtucket, Rhode Island, indicating the possibilities of this approach.

Following this initial spacecraft restraint work, we proposed an enlarged multimanned spacecraft simulator, Fig. 37, for further research on bag materials, multicrew restraint interactions, packaging and inflation and deflation techniques, and reliability tests. We suggested that the front transparent airbag could have an opening for instrument panel access (Fig. 37), with straps

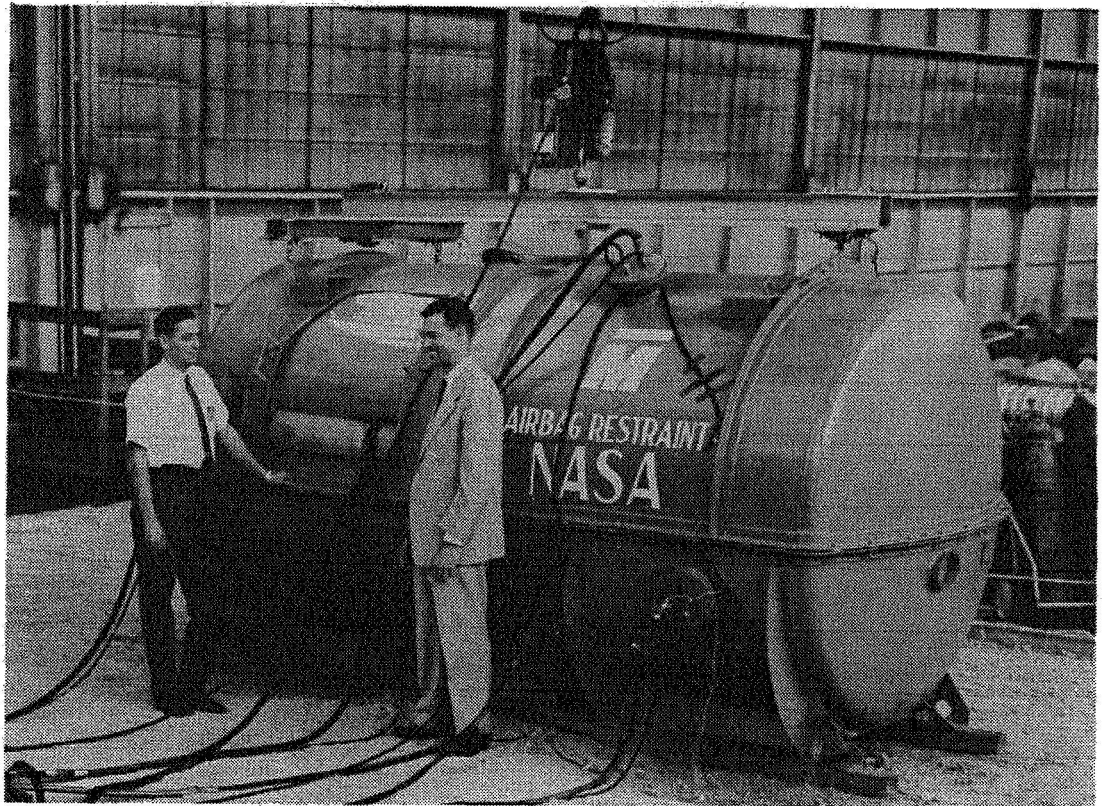


Fig. 32. Martin Spacecraft Simulator Airbag Restraint Experiments, 1964

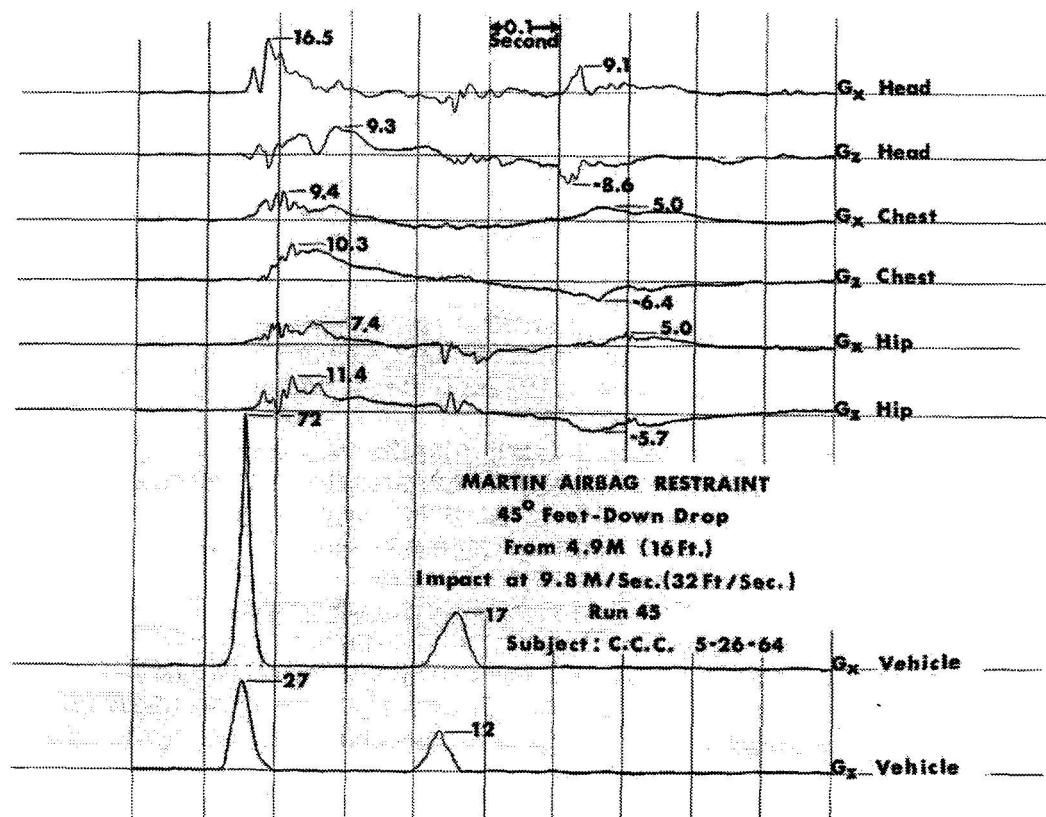


Fig. 33. Accelerations During Manned Impact at 32 Ft/Sec, Vehicle 45° Feet Down

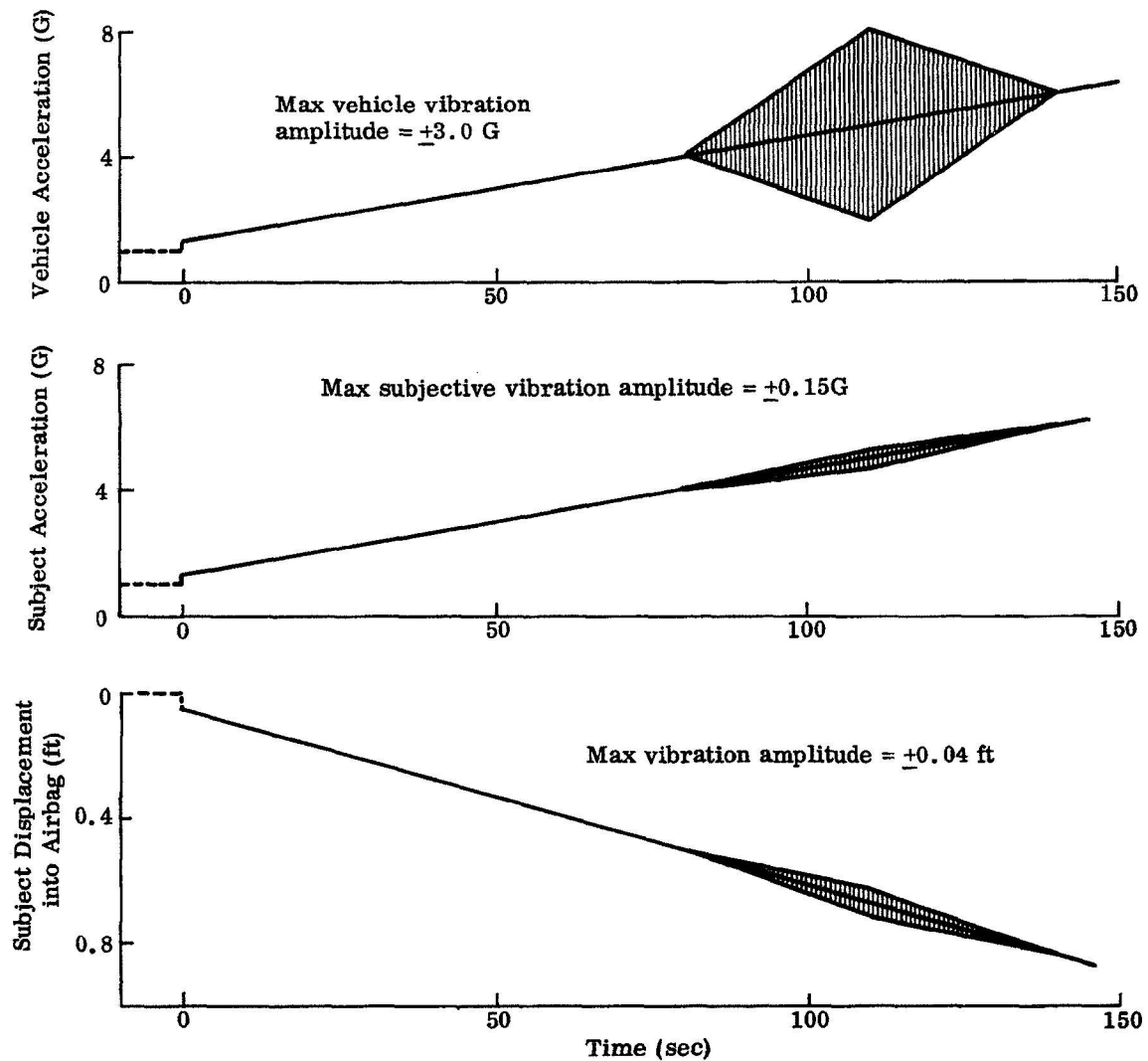


Fig. 7. Accelerations of the Spacecraft and Crew During Launch Vehicle Vibrations--
Analog Program--Pilot Compartment Airbag Restraint System

Fig. 34. Computed Vibration Isolation of the Spacecraft Airbag Restraint

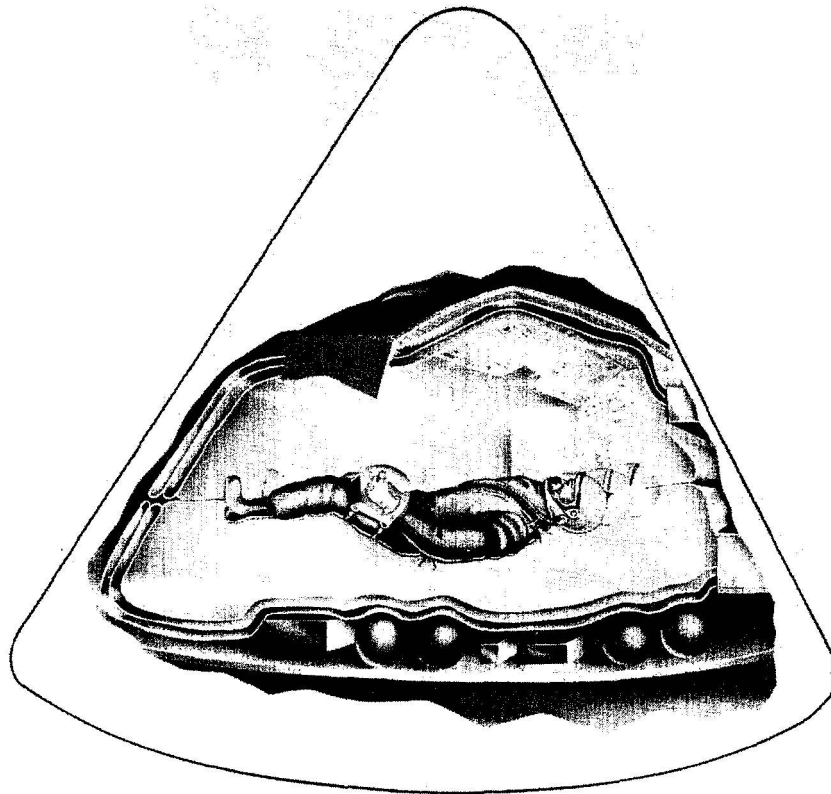


Fig. 35. A Transparent Airbag Restraint System for a Multi-Manned Spacecraft

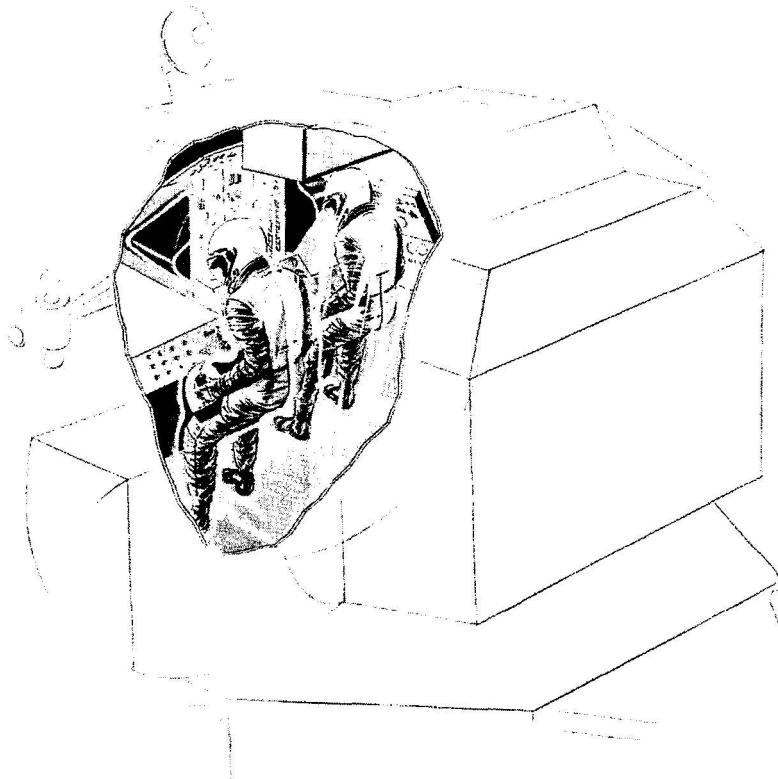


Fig. 36. A Transparent Airbag Restraint System for a Spacecraft Landing Vehicle

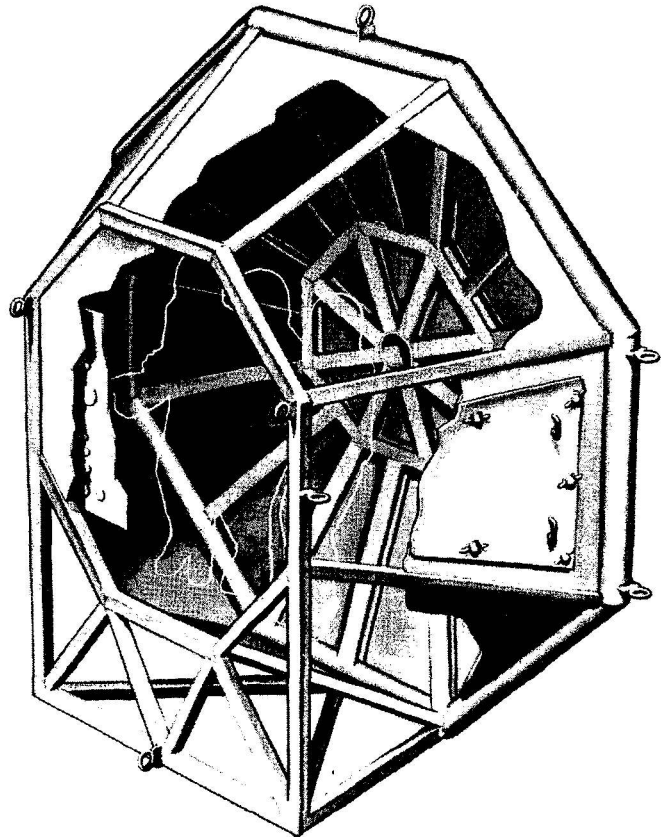
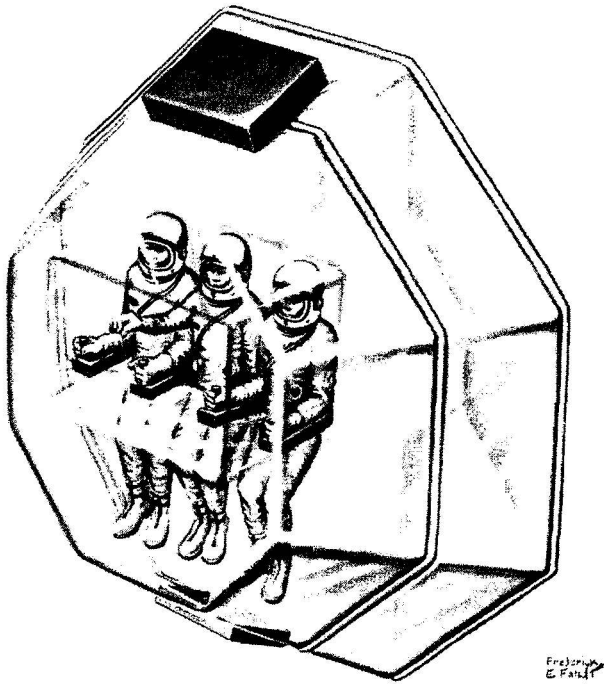


Fig. 37. Airbag Design and Spacecraft Simulator for Proposed Multi-Manned Tests

securing the astronauts to the back bag, giving them the vibration and impact protection of airbags, yet also, by back bag pressure adjustments during boost, full direct panel access. To use this design, controls would either be mounted on the instrument panel or perhaps better on the astronaut, strapped to his leg. To reduce costs, we also proposed to NASA with Air Force cooperation, a joint program with a spacecraft simulator on the Daisy Track at Holloman Air Force Base, to involve multiple chimpanzees and single human tests. However, such further spacecraft airbag restraint research has not been supported.

Note that the high acceleration restraints of spacecraft are needed only during the five or ten minutes of launch and five or ten minutes of re-entry, and particularly during the milliseconds of landing impact. For the rest of the mission time, already two weeks, this grand massive 60G structure, with its couches, sits right in the middle of the road, its function of supporting the astronauts at the instrument panel during 0G or space maneuver loads adequately subserved by much smaller restraint wires or rods. We feel that an airbag restraint system, weighing less than the couch restraint system, could indeed be deflated and rolled up out of the way after the high acceleration periods, opening up the entire spacecraft for 0G experimental equipment, etc. Prior to initiating re-entry, the bags would be repositioned and checked as to pressure tightness. Reserve bags would be available or indeed for the low pressures used (0.3 psig prior to impact, about 1.5 psig peak during impact) could be easily patched. (Note that for a lower cabin pressure than 15 psi, bag gauge pressure would have to be elevated to give equivalent support, which indeed depends on bag absolute pressure, temperature and volume.)

Figure 38 shows a mockup of a partially installed strut-couch restraint system to be used in the Apollo spacecraft. Honeycomb cylinders in the struts are compressed, allowing couch motion and partial load isolation during impact. To prevent loose slapping of the system if there is a second impact inclined to the first, the strut cylinders are clamped after compressing the honeycomb, reducing the load isolation available for the second impact. This couch system has no booster vibration isolation capability. It has been announced that initial plans to land the Apollo spacecraft on land have been abandoned, and water landings will be continued, in part we conclude because of the landing impact hazards. It is hoped that later generations of spacecraft can utilize the load isolation advantages of the airbag restraint system.

Although we have not received support for further spacecraft restraint work, addenda to the original contract have allowed us to experiment with an aircraft passenger airbag restraint system, considered in the bulk of this report, study applications of airbag restraints to other transportation vehicles, including the automobile,^{15, 79} and experiment with an "Airlitter" for transportation of the injured,⁸⁰ briefly described below. These addenda apparently were initiated by the interest of Jerome Lederer, Director of the Flight Safety Foundation, perhaps remembering Jordanoff's ideas. The Aviation Safety Engineering and Research (AvSER) group of the Flight Safety Foundation was preparing to carry

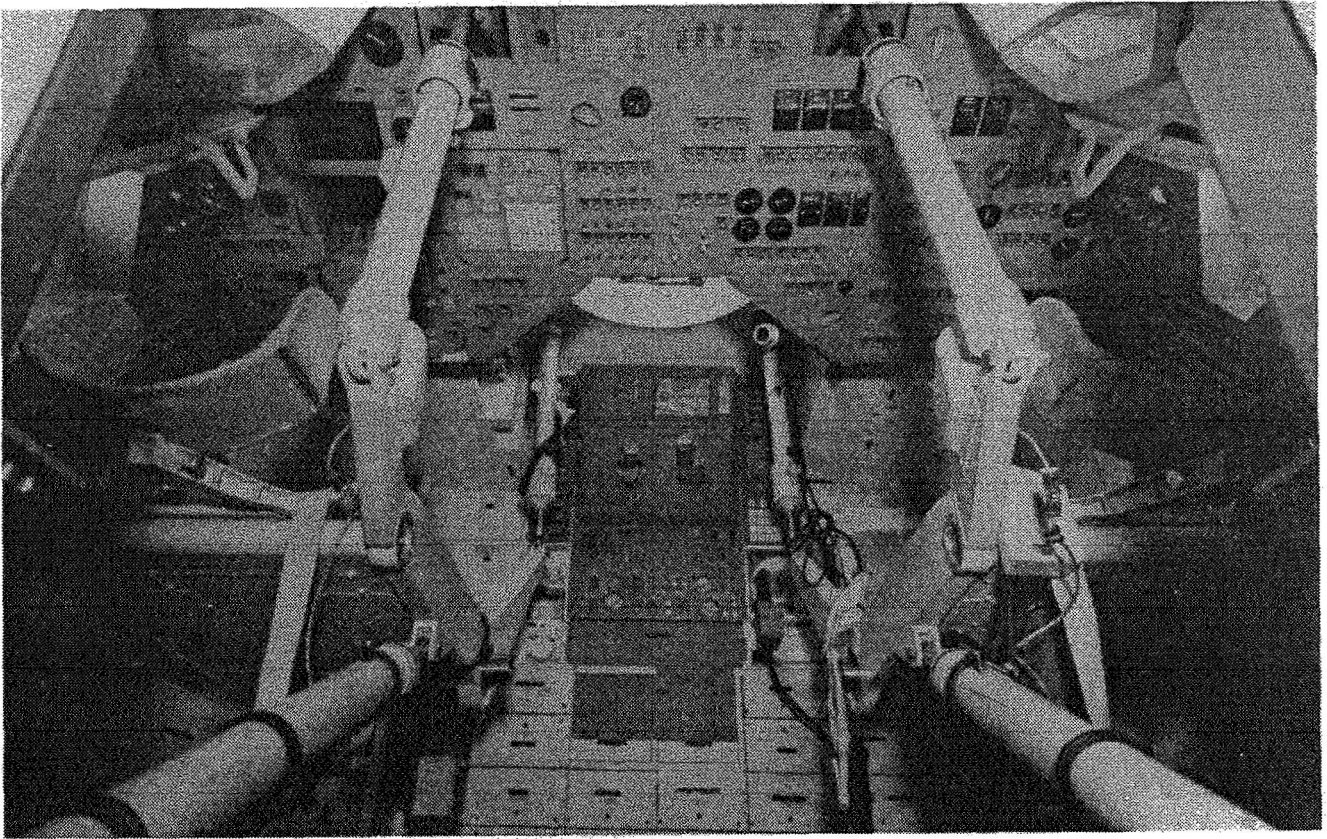


Fig. 38. The Apollo Strut Impact Attenuation System, Early Mockup
with Central Couch Removed

out for the Federal Aviation Agency two controlled transport aircraft crashes, including seating and restraint tests. Mr. Lederer suggested to NASA that airbag restraints might be added to these tests, and this subsequently occurred, as discussed below. We express our appreciation to Mr. Lederer for his interest.

We note that our work and the initial support on airbag restraints were initially directed to the spacecraft application. We now see its greatest potential for lifesaving in automobile applications. If this indeed develops, it will be an excellent example of how work initially developed for space can find its later far more extensive application for the general public.

E. THE AIRLITTER APPLICATION

The concept of an Airlitter, or inflated structure for the transport of the injured, came to us during work with the "body bag" built during the spacecraft airbag restraint program to take the function of an astronaut pressure suit. This body bag had a high pressure limited distension outer shell and a low pressure inner bag for body support. In the body bag with outer shell at 5 psig, the pressure on the man could be the few inches of water pressure of the inner bag, yet the spacecraft restraint airbags could be at 4.5 psig, for example, if this high a pressure were needed in adjusting the restraint characteristics.

With such a double-walled structure of an Airlitter, the outer wall or high pressure airbag could provide stiffness and local load isolation in carrying an injured person or transporting him on an irregular surface such as the back of a truck, and the inner wall or low pressure airbag can provide both additional static load isolation (if the Airlitter were resting on a jutting rock) and moderate dynamic load isolation as well as body support for oblique loading (as in going down stairs) by broad surface support rather than by tight straps. On deflation, the entire structure could be rolled into a small size. The concept was presented to NASA for brief development and testing, and an addendum to NASA contract NASw-877 to cover the Airlitter work was granted. This work is reported in full separately,⁸⁰ but is noted here for completeness of review of the contract work.

To minimize costs, commercial air mattresses were utilized to make the outer wall, with latex airbags for the inner support (Fig. 39). This Airlitter was swung into a barrier at 19 fps velocity, with the skid receiving over 80G, yet the accelerometer on the subject's head peaked at 7.2G (Fig. 40). The Airlitter was dropped from various heights and was in the cabin of a CH-21 helicopter dropped from a height of 30 ft by a crane moving forward at 30 mph by AvSER (Flight Safety Foundation) for the Army. The litter remained inflated and the dummy loads appeared survivable.



Fig. 39. Martin Airlitter Experiment

Figure 41 is an artist's concept of a lightweight Airlitter, perhaps to have a battery powered ventilation fan. During transport, the litters could be stacked in trucks or aircraft without special racks. The litter would unzip in the field hospital to provide two beds. We have not yet obtained support for further work on this concept.

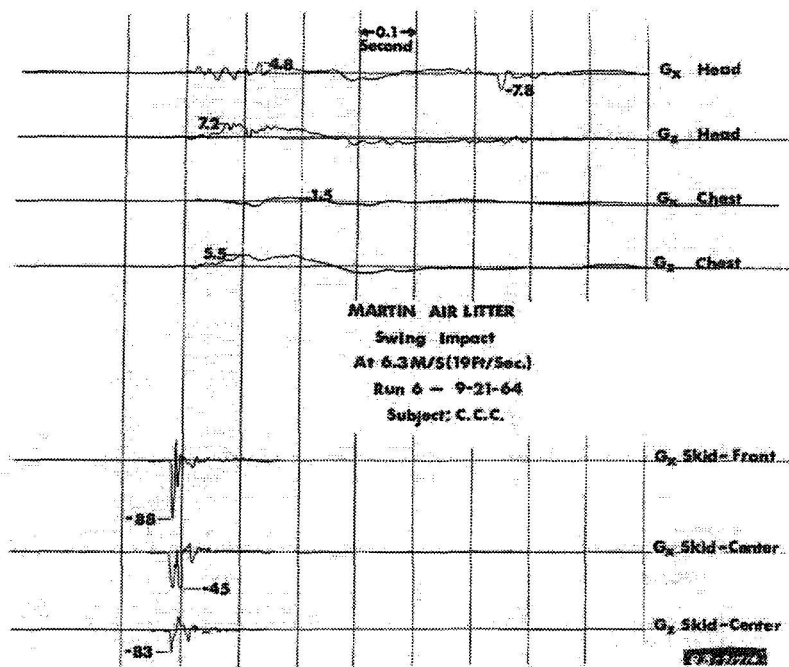


Fig. 40. Accelerations in the Airlitter Impacting by Swing at 19 Ft/Sec

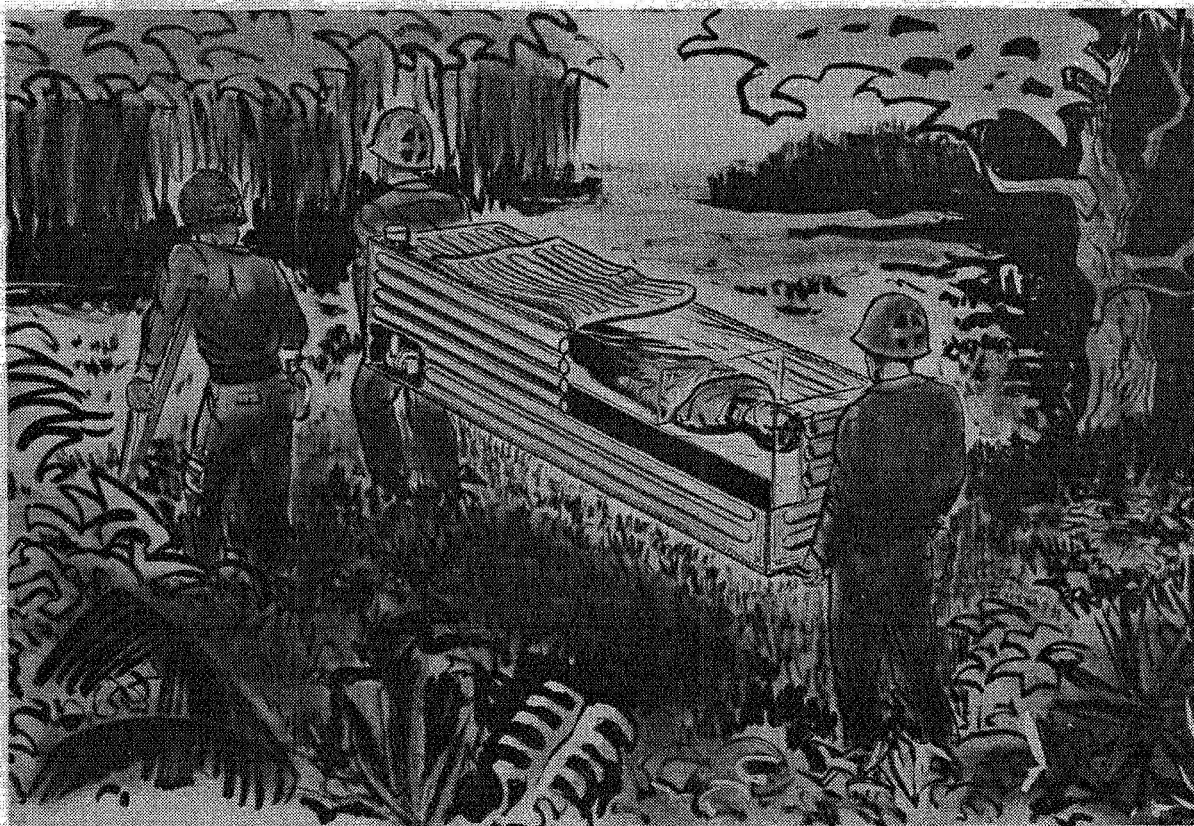


Fig. 41. A Proposed Improved Airlitter Design

III. DEVELOPMENT OF AN AIRCRAFT PASSENGER AIRBAG RESTRAINT SYSTEM

A. THE NEED FOR RESTRAINT

Transport vehicles would perhaps need no restraint (other than seats to support against the 1 G of gravitation) if they never exceeded 0.05 g acceleration in changing velocity or perhaps even 0.1 g if they never exceeded 0.01 g/sec, with a reliability of perhaps one case twice as bad as this per 10^6 trips and one case ten times as bad as this per 10^9 trips. At perhaps 0.05 g slowly applied, the general public could probably stay standing, as some might at 0.1 g slowly applied. Above 0.1 g some would slide off seats.

One can do a lot with 0.1 g (2.2 mph/sec): in a thousand seconds (17 min) one is at 2200 mph, and in another 17 min one could stop again, still never having exceeded 0.1 g of displacement acceleration, having traveled 600 miles. One must turn corners very carefully as well as start and stop carefully; at 1000 mph a "corner" must have a radius of over 125 miles to be turned at less than 0.1 g. In the meantime, transport vehicles will need restraints.

The extent of the needed restraint should depend on the worst case of starting or stopping in perhaps 10^9 trips. We say 10^9 because a man might make 0.02 to 1×10^6 "trips" in a life span, and we'd like the probability of his getting killed on any trip during his entire life span to be something less than 10^{-3} , not the one chance in forty of being killed during a life span with an automobile which we now face.¹⁵ Since man's acceleration tolerance is limited (though Col. Stapp⁵⁰ has taken $-45G_x$ in stopping from 50 mph without injury, and $-45G_x$ in stopping from 120 mph with only reversible eye injury, and Capt. Eli Beeding has taken $83G_x$ in stopping from 40 mph with reversible injury⁸¹) and the strengths of his vehicles are limited, clearly more than good restraints are required to ensure that he would probably survive 10^9 trips. If the vehicle is never to exceed say $45G$ in any accident in 10^9 trips, the probability for example for automobiles of having head-on collisions with both cars moving at 45 mph or faster must be below 10^{-9} , a sizable task to attain. But just as it is clear that aspects of transportation safety other than the restraints must be improved before we can attain the goals discussed, it is also clear to us that restraints (and passenger compartment strengths) supporting the human at least up to his tolerance levels, in that these can be foreseeably provided--by the air-stop system for example--should indeed be provided before the other far more difficult and costly improvements which contribute to safety are attempted, such as ensuring that cars never collide head-on. It is our view that at least for automobiles and aircraft, and with other elements of the safety system as they are now, the lives saved per dollar spent on safety will be greatest if those first dollars are spent on improved restraints. We hope in the near future to assemble data on the life saving cost effectiveness of safety improvements, to show whether indeed this view is correct.

In the meantime, our goal here is to provide a restraint which will protect a man up to his internal injury tolerance levels. We want this restraint out of the way when not in use, rapidly deployed in an emergency, providing full body support, and to the extent possible in terms of displacement room in the passenger compartment, providing load isolation for high frequency (short duration) load events. The rest of this section outlines our steps in working toward such a restraint.

B. INITIAL SWING AND DROP TESTS

In February 1964 the scope of the basic contract (space application of airbag restraint systems) was broadened to include the commercial airline passenger restraint system, and participation in the full scale testing of the system during two planned airplane crashes by the FAA (Contract NASw-877, Addendum 1).

To evaluate the Airbag Restraint System for longitudinal impact protection, an impact skid was fabricated from steel tubing with provision for mounting two pairs of standard airplane seats to a 0.75-in. thick plywood deck. Figure 42 shows the skid details for reworking to accommodate the airseat that was added later in the program. The skid, with the mounted restraint system, was supported by a 4-point sling (Fig. 43), and suspended from a boom crane that positioned the skid approximately 1 ft above ground level and immediately in front of a concrete wall with a 2 x 10 wooden bumper between the skid and concrete. The skid bumper was a welded-in-place, 6-in. square steel tubing that ran the full width of the skid. To achieve somewhat extended pulse durations, tests were conducted with styrofoam, wood, and paint cans positioned on the skid bumper. Figure 44 shows one of the cans in place.

With the restraint systems pressurized and the subject in place, the skid was pulled back toward the boom of the crane until the desired height was obtained (Fig. 44). A manual quick release hook was then actuated allowing the skid to swing into the concrete wall. Impact velocities up to 19.6 fps were obtained in this manner.

The instrumentation schematic of Fig. 45 shows the basic setup used. Skid accelerations were measured using Statham Model A5A transducers. These accelerometers were oriented for measurement in the G_x , G_y , and G_z axes and were located near the point of impact and at the base of the seat structure. Subject instrumentation consisted of Statham F-50-300 accelerometers, mounted on the chest and hip for measurement of G_x and G_z accelerations. Dummy instrumentation consisted of Statham A5A accelerometers mounted in the head, chest, and pelvic regions for measurement of G_x , G_y , and G_z accelerations.

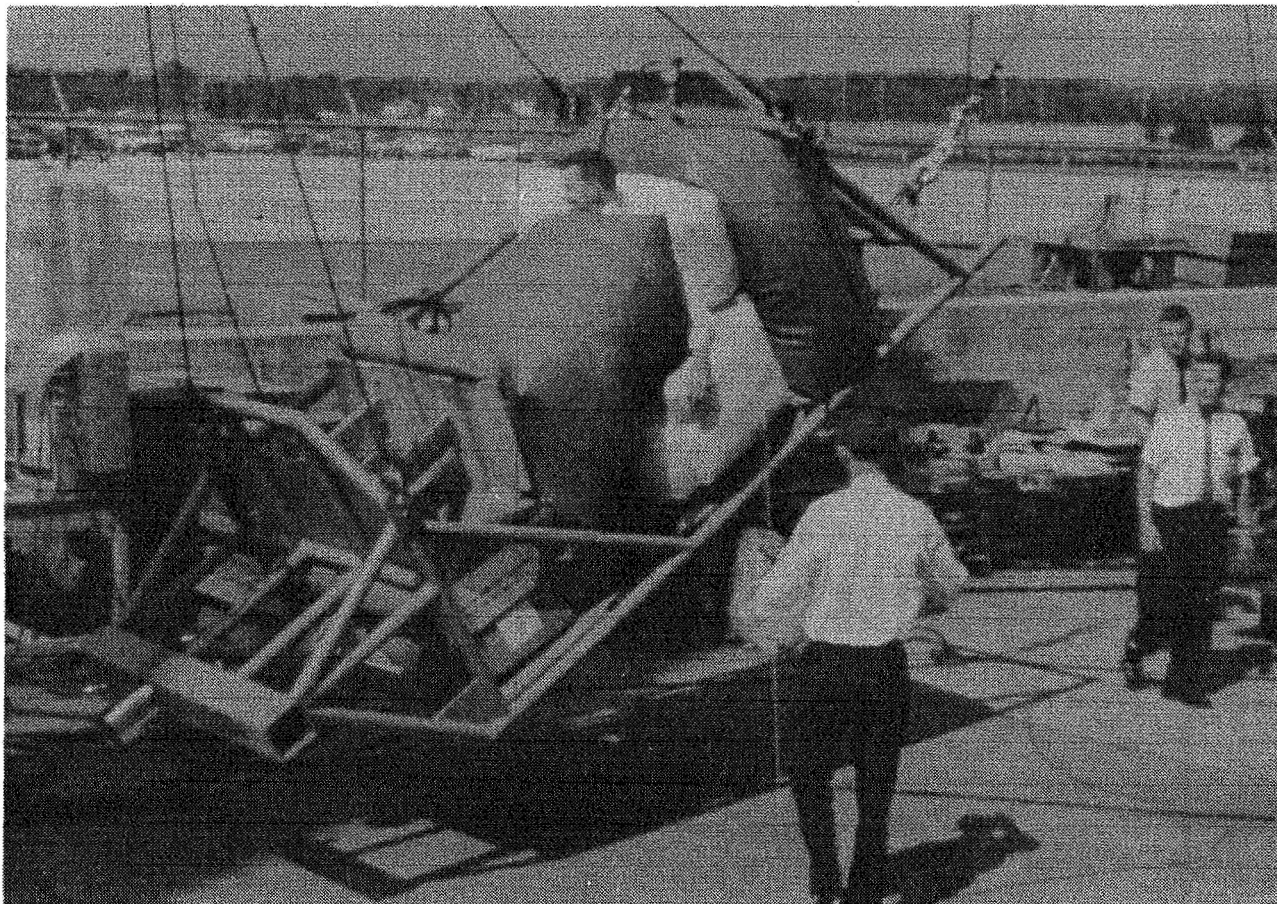


Fig. 44. Swing Impact Rig at Pullback Height Prior to Release (manned experiment)

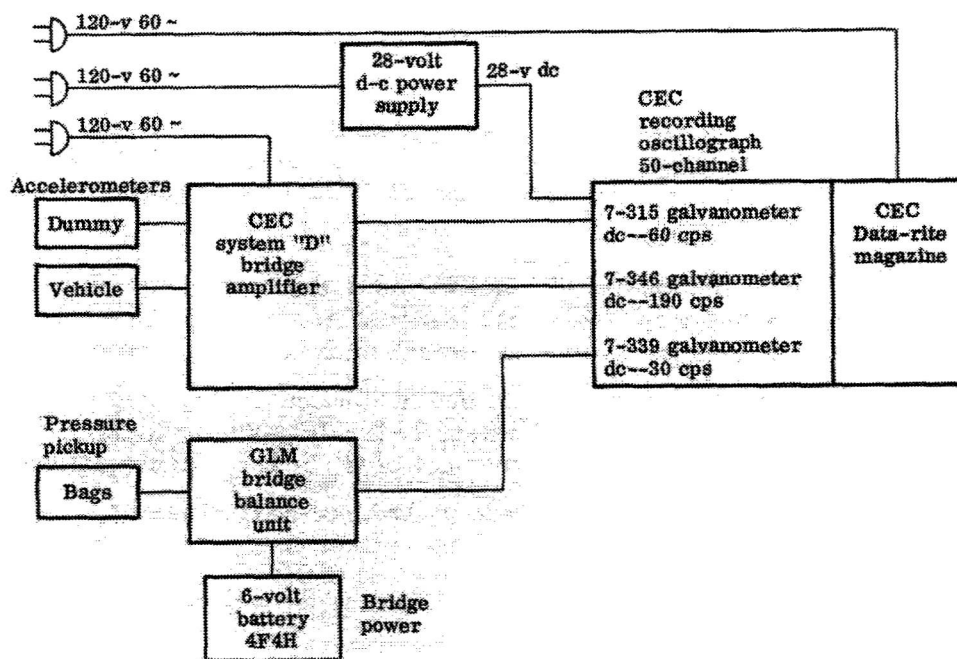


Fig. 45. Instrumentation Schematic

In an airplane or automobile with passengers using lap belts but no upper body support, moderate to severe crashes (such as indicated in Fig. 46) produce body buckling about the lap belt, snap loads when reaching the end of any lap belt slack and leg swing-up loads which contribute to tearing out the seats and may contribute to lap belt failure (which did occur with metal failure at the belt attachment to the seat in this run), and head and limb impact with the seat in front, with the head in this run exceeding the transducer-recorder limits of $-25G_x$ and $-15G_z$ (Fig. 47). With upper body and feet airbags (Fig. 48) and with the lap belt purposely loose, the body as a unit slides forward on impact, hence experiencing significant load isolation (Fig. 49). With no dynamic overshoot or snap loads being transmitted to the seat, the seats are less likely to tear loose. Motion into the chest airbag approaches the resonance frequency response of the man-bag system, near 2 to 3 cps, so that acceleration onset rates of the man are not significant to tolerance. Moreover this low frequency of the principal body motion means that the head would not snap forward even if inadequately supported by the airbag as is confirmed by motion pictures of a human impact test with unsupported head. The initial load is followed by a rebound load back into the seat. The particular seats used had a frame structure into which one bottomed somewhat on rebound; note that the rebound head and chest G_x values (Fig. 49) are slightly greater than the initial loads. Subjectively such crashes are of such brief duration that although one is aware of the rebound, the feeling of the crash is of a single experience, generally acceptable. (One slight headache after one of these runs was the only physiological decrement experienced in this entire program.) These seat bottoming loads led to our desire to be surrounded in all directions by controlled yielding (or active elastic) materials, contributing to our concept of an airseat, as part of the airstop restraint system discussed below.

In order to obtain more severe down loads ($+G_z$) and to obtain a secondary impact as frequently occurs in a crash, we made a five foot drop of the crash rig by a crane onto a skid on a hill (Fig. 50), with the crash skid and wooden frame hill skid rolling together down the hill for the secondary impact. The dummy received significant support and load isolation (Fig. 51) by sliding forward and down onto the foot bags (one in front and one behind the feet, extending under the seats). On the rebound, head instrumentation was briefly lost, but again head rebound loads would be significantly reduced if the rebound was into a softer seat structure. We lost crash skid instrumentation, but this drop method, used with various steeper hills, does appear to be feasible and an inexpensive way to obtain approximate simulation of multiple crash loadings. We do not know of previous uses of this method for crash load simulation. The pertinent test data from this series of experiments are shown in Table 7.

Experimental work, primarily static pressurization tests, was conducted to make an airbag out of other material than 15 layer sprayed latex (15 pounds per passenger), with rubberized nylon (8 pounds per passenger), transparent 8 mil polyvinyl chloride (5 pounds per passenger) and 1 mil mylar (1 pound per passenger) bags being examined. We are particularly interested in transparent bags

TABLE 7
Test Data--Swing Impact Tests, Chest Airbag Without Airseat

Run No.	Condition					Longitudinal Accelerations ($-G_x$)			
	Impact Velocity (fps)	Impact Material Between Skid and Wall (inches of foam)	Airbag Type	Static Pressures		Head	Chest	Hip	Seat (4 millisecc period haversine)
				Chest (in. H_2O)	Foot (in. H_2O)				
28	16	8	Latex	3	3	-11.6	-8.7	-12.5	
29	16	8	Latex	3	3	-11.0	-9.2	-11.2	$\approx -30.0 G_x$
30	16	8	Latex	3	3	-11.7	-7.5	-10.0	≈ -30.0
31	16	8	Latex	10	10	-10.7	-7.4	-9.9	-27.4
32	16	8	No airbags	--	--	-25**	-7.5	-14.6	-30.0
25*	11.3	None	Latex	3	6	--	--	--	≈ -25
34	18.0	Inclined drop	Latex	10	10	-12.7	-3.0 +12.7 (rebound)	-3.0 +4.0	--

*Manned Test

**Out of Instrumentation Range

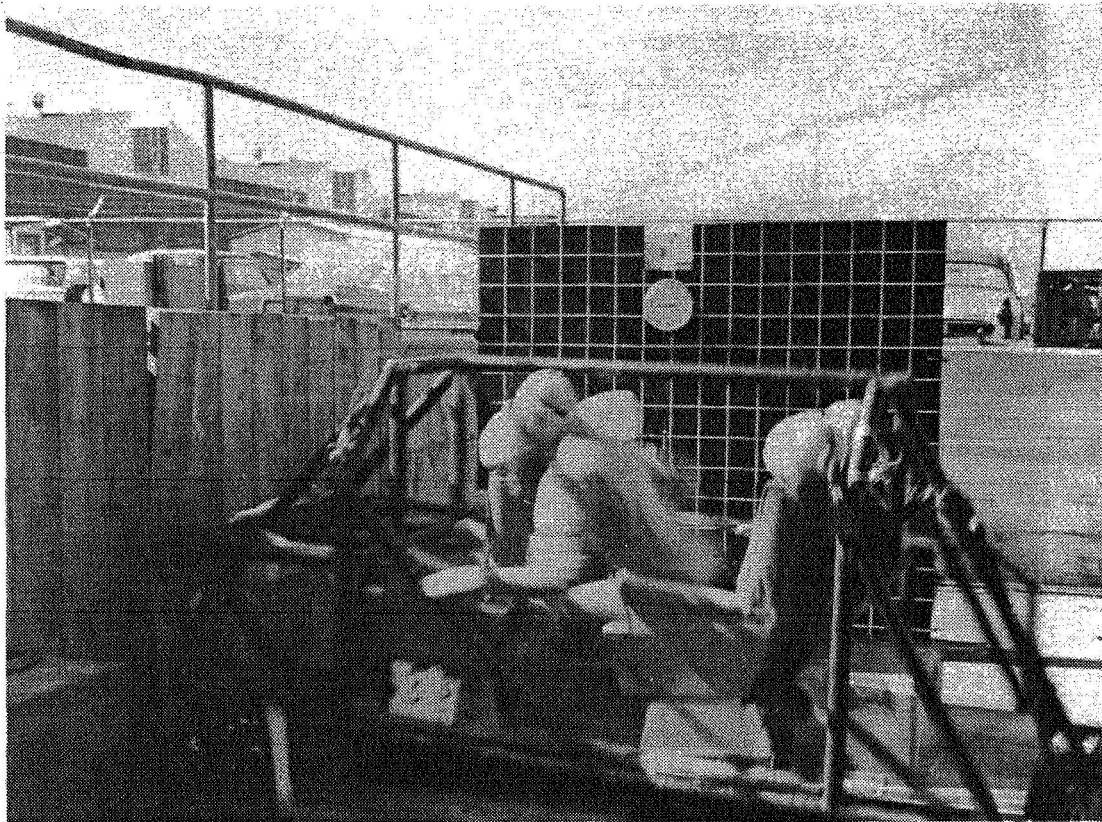


Fig. 46. Swing Impact with Lap Belt Restraint (impact velocity 16 ft/sec, dummy subject)

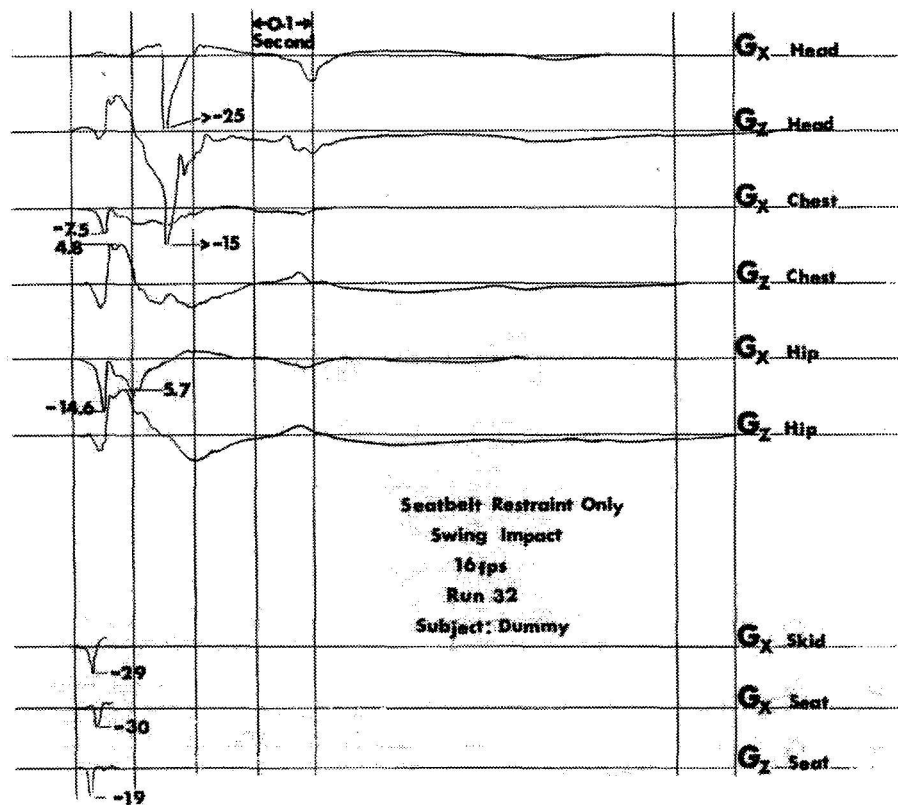


Fig. 47. Acceleration Time History--Swing Impact with Lap Belt Restraint (impact velocity 16 ft/sec, dummy subject)

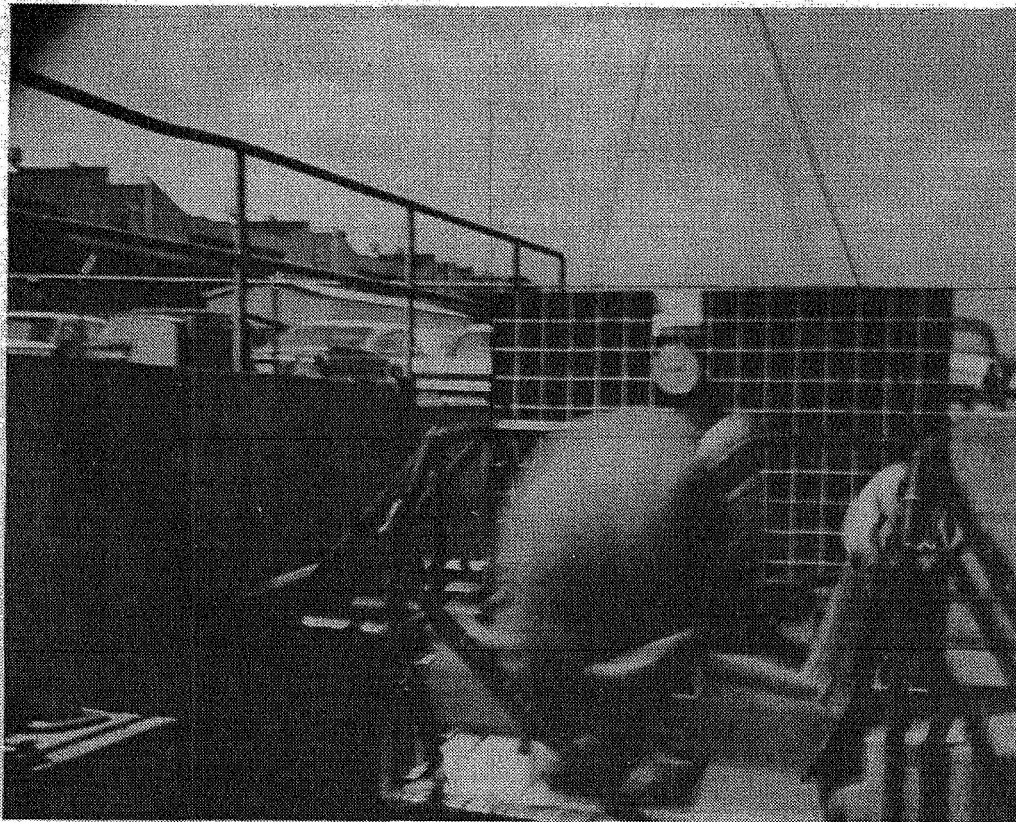


Fig. 48. Swing Impact of the Airstop Restraint Without the Airseat (impact velocity 16 ft/sec, dummy subject)

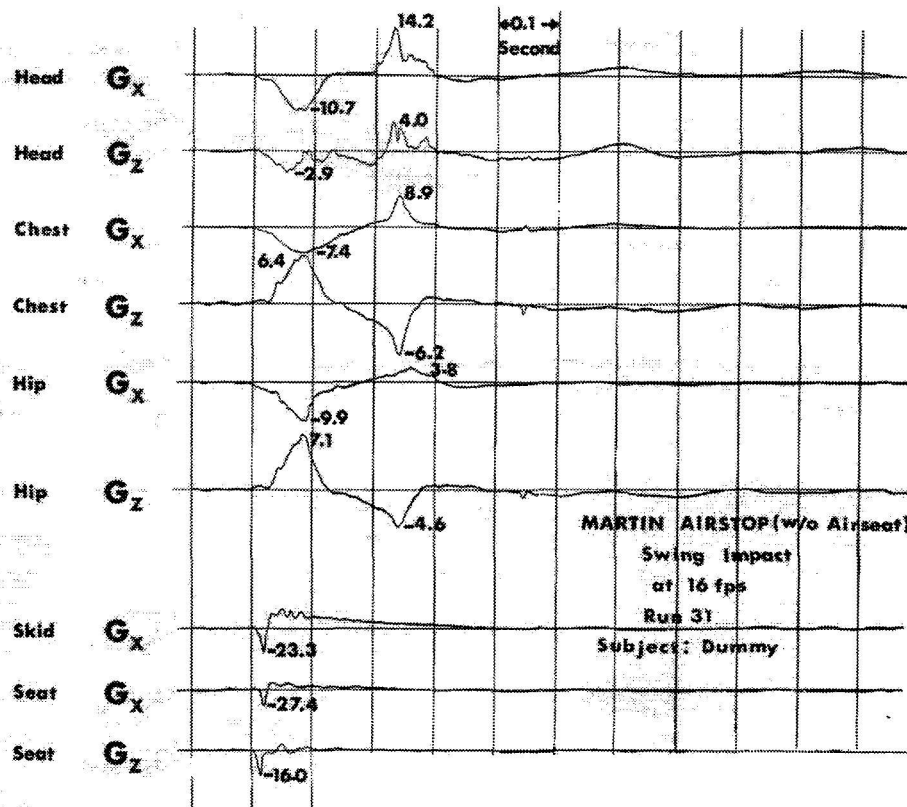


Fig. 49. Acceleration Time History--Swing Impact with the Airstop Restraint and Without Airseat (impact velocity 16 ft/sec, dummy subject)

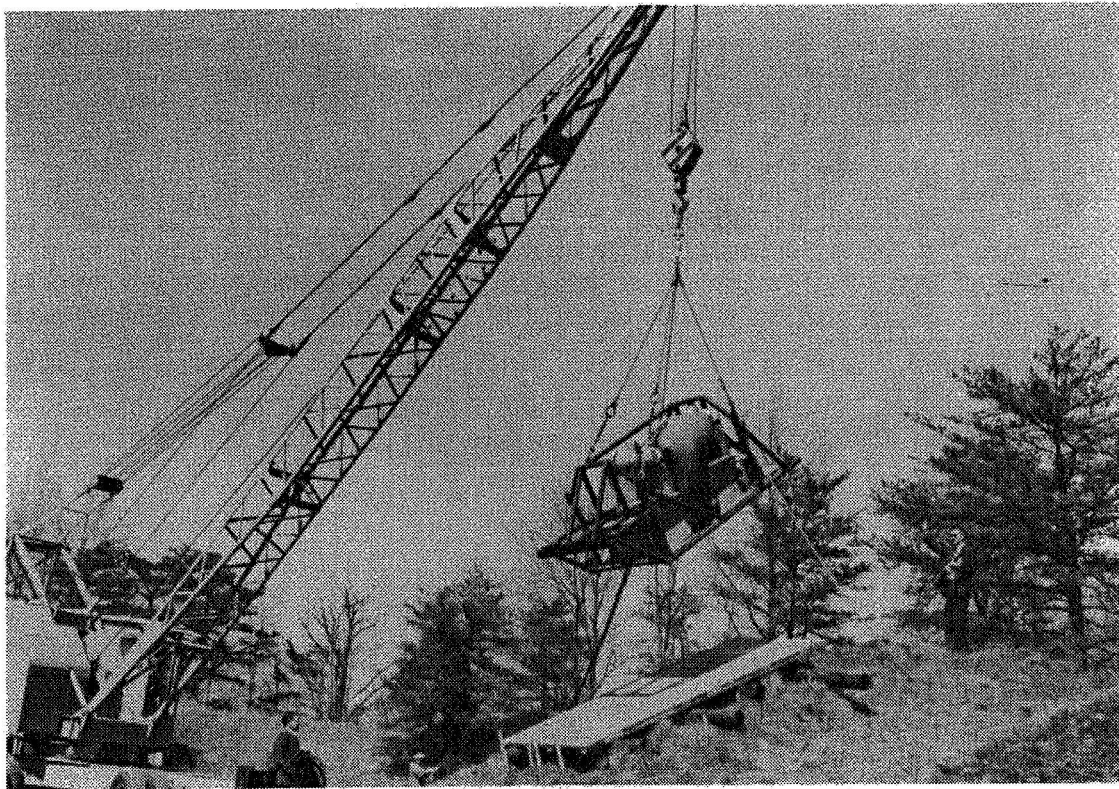


Fig. 50. Crane Drop Onto Hill Skid with the Airstop Restraint and Without Airseat (impact velocity 18 ft/sec, dummy subject)

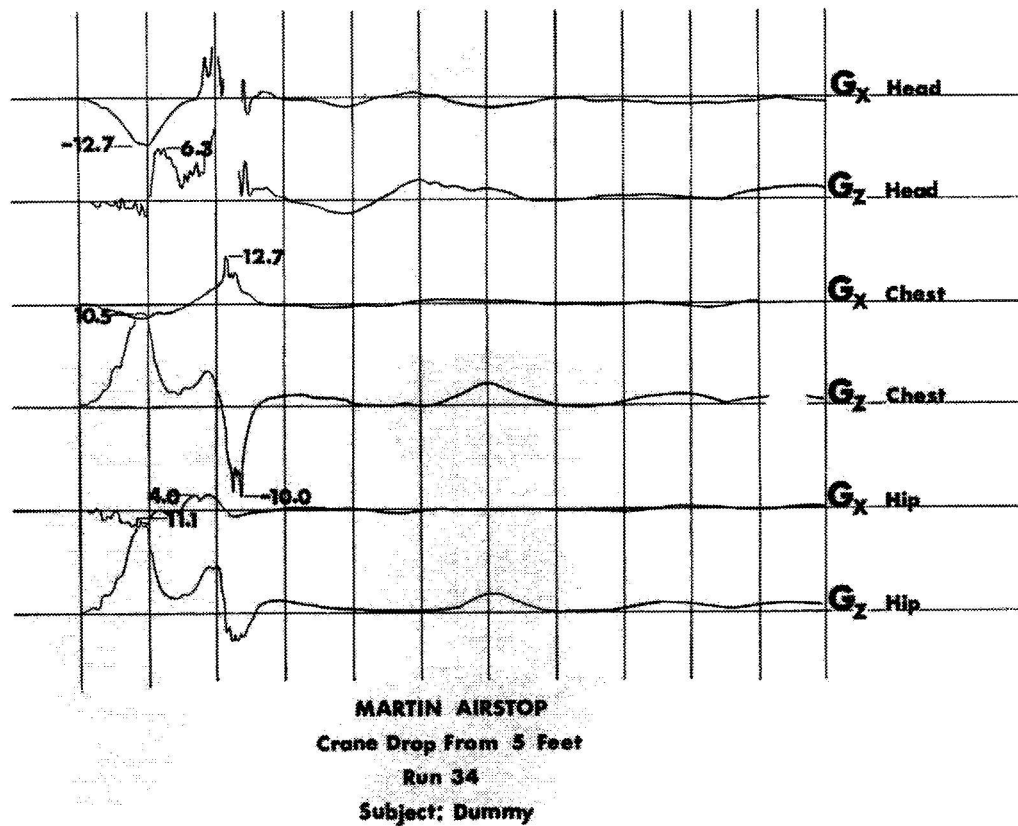


Fig. 51. Acceleration Time History--Crane Drop Onto Hill Skid with the Airstop Restraint and Without Airseat (impact velocity 18 ft/sec, dummy subject)

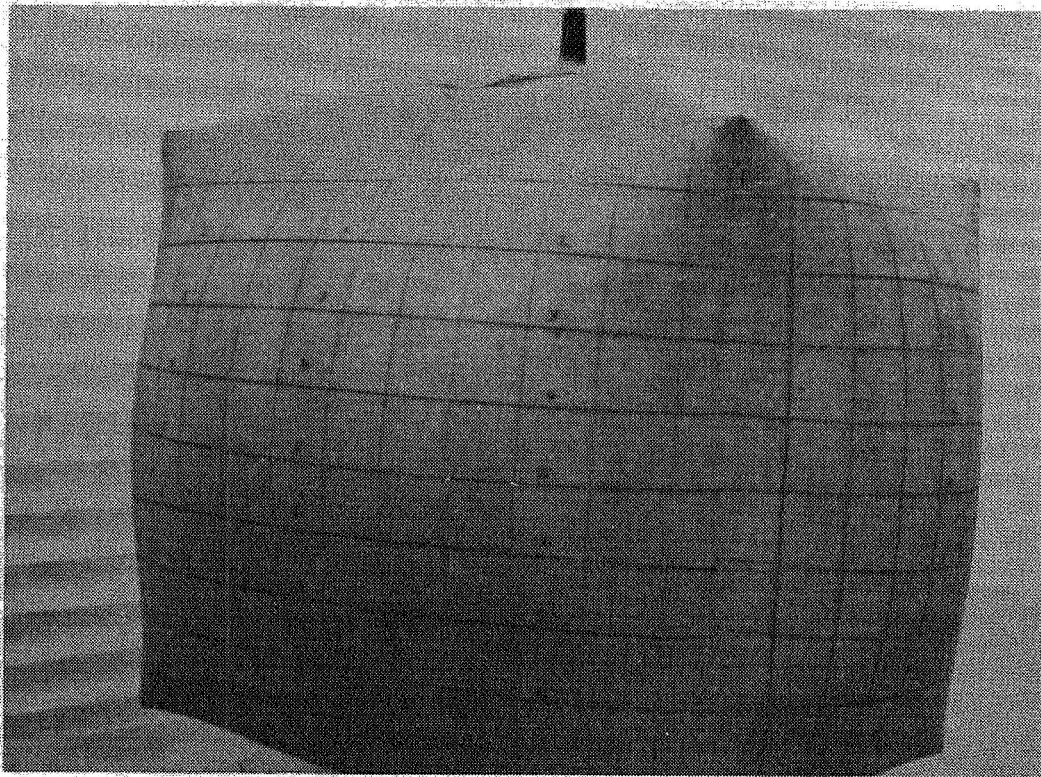


Fig. 52. Latex Airbag for Static Loading to Determine Load Deflection Characteristics

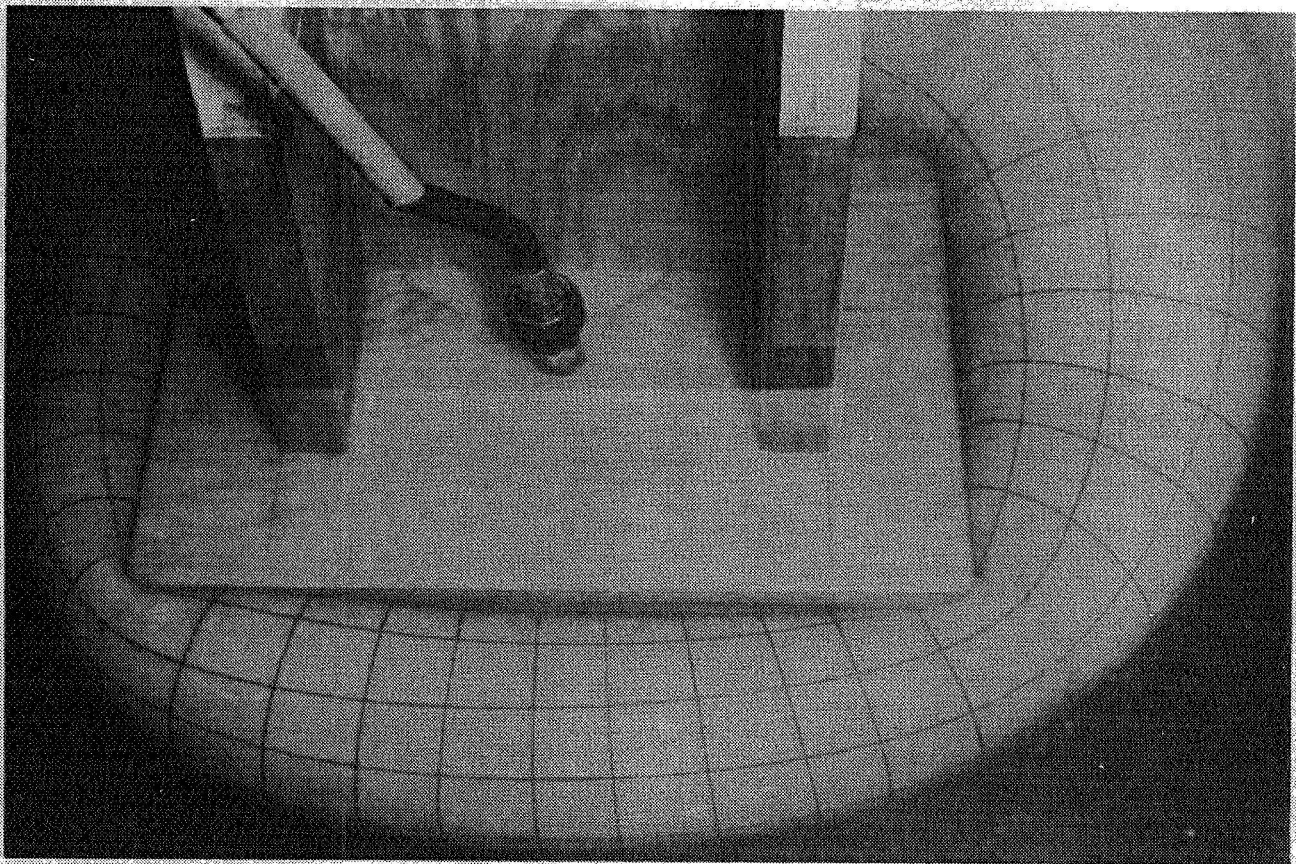


Fig. 53. Latex Airbag for Determining Load Deflection Characteristics Shown Under Load in Test Machine

for this significantly reduces claustrophobia; mothers can see children and purses, stewardesses can see passengers, etc. In our test crashes, with initial bag pressure generally at about 6 in. of water (0.2 psi), peak pressure on impact with the elastic wall latex bags does not exceed 1.5 psi. We have had seal failures of our more rigid wall plastic bags. However, an excellent chest bag of 5 mil elastomeric polyvinyl chloride of 17.5 x 20 x 34 in., sealed electronically, weighing two pounds and able to sustain 5 psi gauge, has been made for us by the Lindron Company (Mr. Al Elkin), Pawtucket, Rhode Island, which was used in the second airplane crash (see below). We are encouraged that strong, light, transparent, probably elastic plastic bags can be produced for the chest and foot airbags.

Static load deflection characteristics for latex airbags of varying sprayed layers and an elastomeric vinyl bag were obtained. These bags were approximately 8 x 10 x 12 in. in size (Fig. 52), and were loaded statically on the 8 x 12 in. face (Fig. 53).

These load deflection curves along with the adiabatic piston model and a test on the full scale chest airbag are shown in Fig. 54.

C. THE DC-7 CRASH TEST OF APRIL 1964³⁶

On April 24, 1964, a DC-7 was experimentally crashed in Phoenix, Arizona, by the AvSER (Aviation Safety Engineering and Research) group of the Flight Safety Foundation under the direction of the Federal Aviation Agency, with instrumentation and cameras supplied by the Army and Navy, and with cooperative experimentation by the Flight Safety Foundation, FAA, Army, Navy and NASA. The NASA airstop restraint experiment consisted of two dummies in the rear compartment, one behind a latex chest bag and the other by the window behind an 8 mil (0.008-in. wall thickness) transparent polyvinyl chloride chest bag (Fig. 55). The lap belt of the latex bag restrained dummy was loose about 12 in. Its feet were restrained by "foot bags" under its seat and under the seat in front (Fig. 56). The dummy behind the vinyl bag had a tight lap belt and no foot bags. Camera coverage was provided only for the latex bag dummy since it had not been initially planned to try the vinyl bag. Bags were not included in the immediately anterior and posterior seats, so that less than the rebound protection of the full airstop system was provided in this test. A comparison dummy, restrained by a tight lap belt, was across the aisle. In back of this was a dummy on a side facing seat, restrained by a lap belt, an FAA experiment. (Its feet can just be seen behind the technician in Fig. 55.)

The airplane nose wheel was guided on a track; the four engines were manually run up to full thrust. The pilot then left the airplane (Fig. 57), a clamp was released, and the airplane went down the track. A moderate tail wind brought velocity at impact up to 160 mph. The wheels and propellers were sheared by barriers (Fig. 58). The right wing hit two telephone poles in FAA gasoline containments tests involving colored water in the tanks. The left wing tip hit a small hill (Fig. 58), and the airplane hit near the top of a first hill 25 ft high of 125 feet length at 8° slope (Fig. 59). It then flew some 200 ft to a second hill 42 ft high at 20° slope, whose top was some 530 ft from the

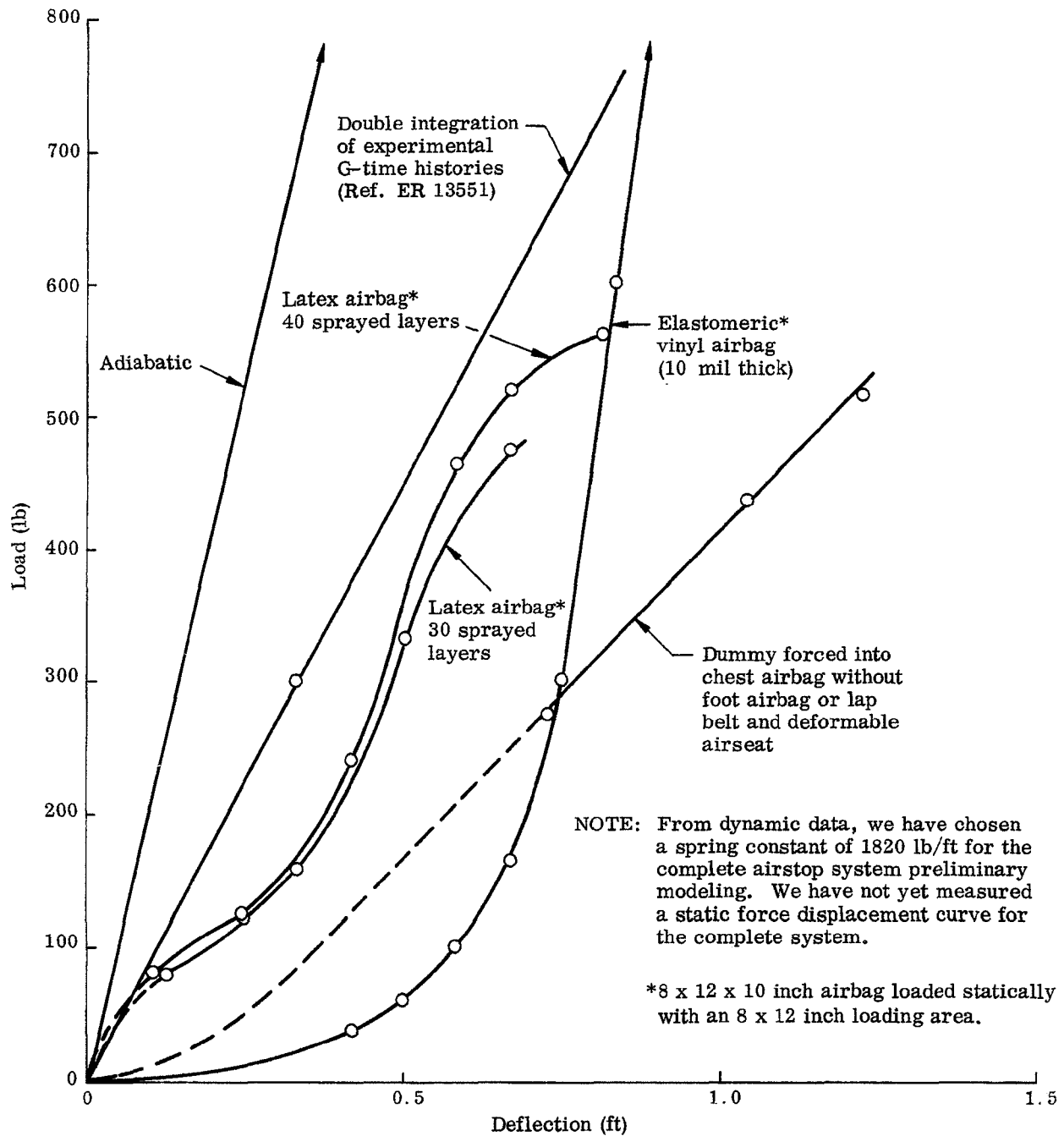


Fig. 54. Load Deflection Characteristics of Latex and Elastomeric Vinyl Bags

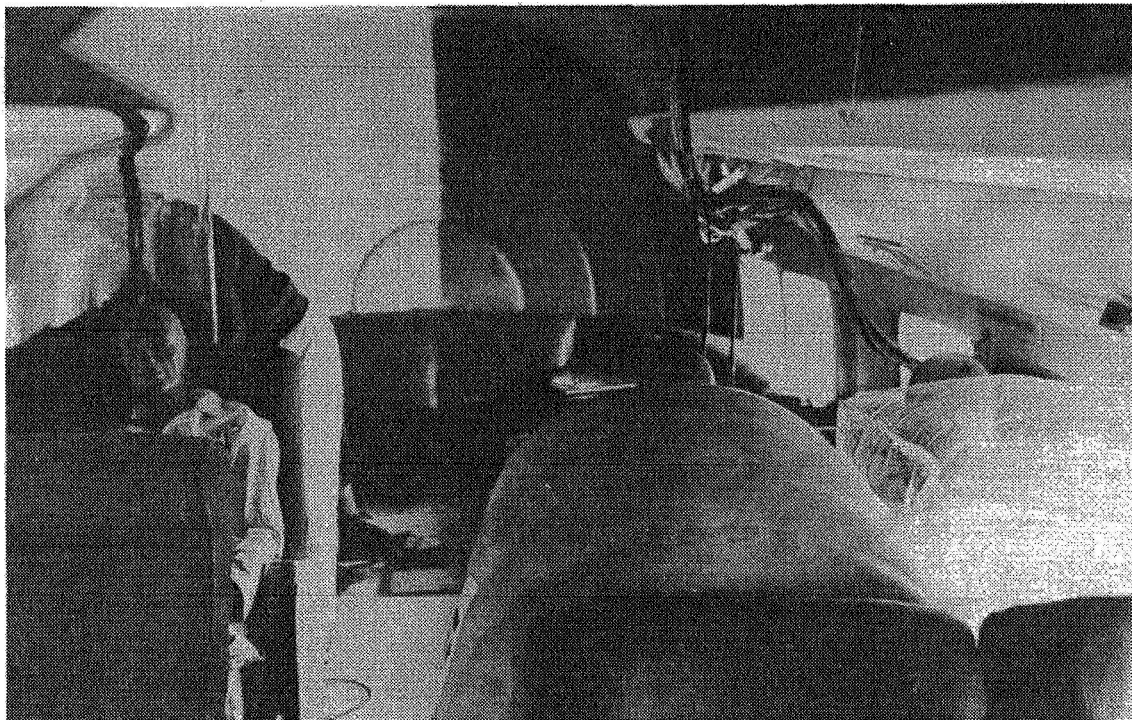


Fig. 55. DC-7 Interior Before Impact Showing the Dummies with Latex and Vinyl Chloride Airstop Restraints on the Right and the Comparison Dummy with Lap Belt Restraint on Left (courtesy of the FAA)

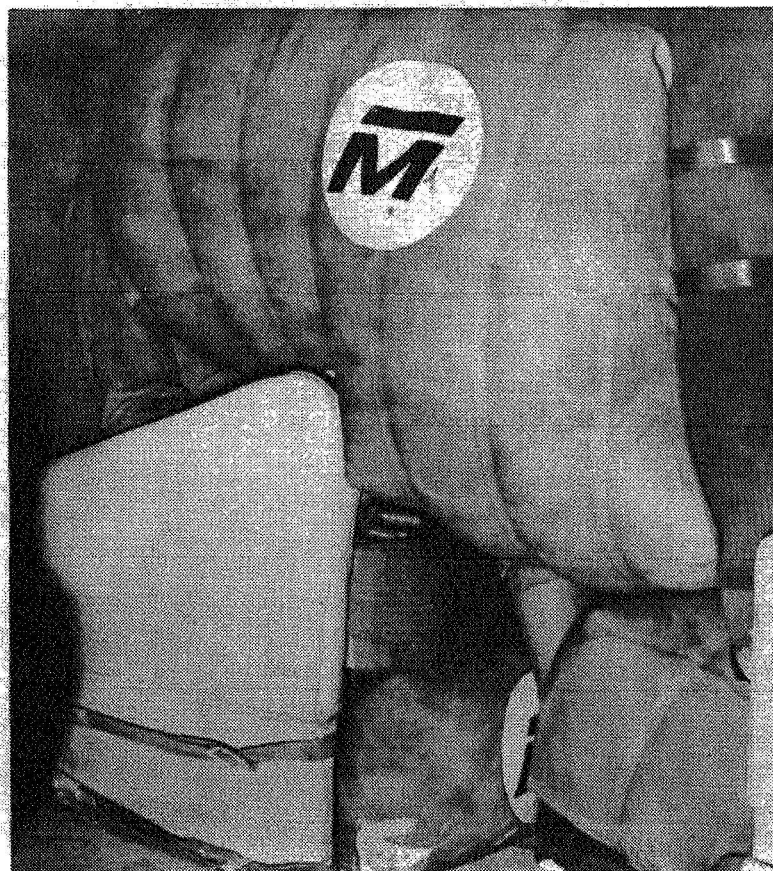


Fig. 56. DC-7 Interior Before Impact Showing the Dummy with the Latex Airstop Restraint (courtesy of the FAA)

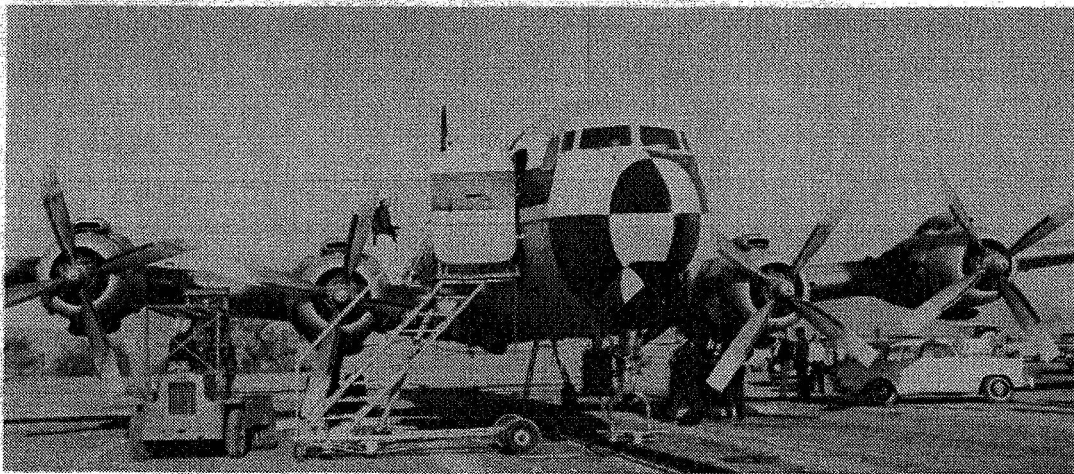


Fig. 57. DC-7 Exterior Showing the Nose Wheel Guidance Rail (courtesy of the FAA)

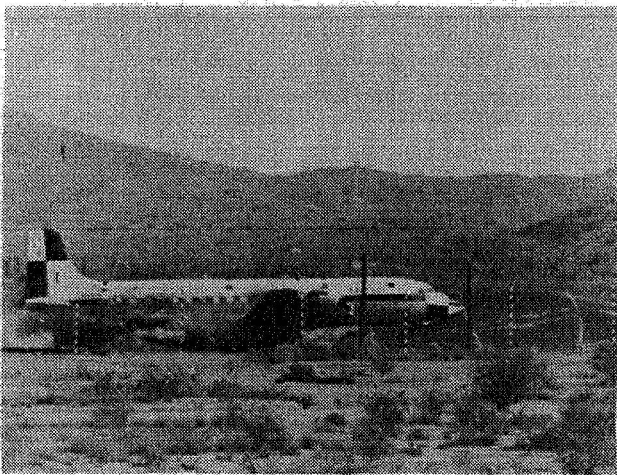
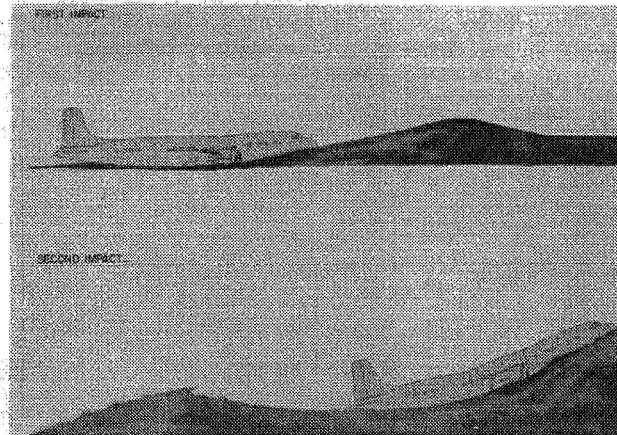


Fig. 58. The DC-7 Shearing Wheels and Propellers at 160 Miles per Hour (courtesy of the FAA)

Fig. 59. Major Fuselage Impact Slide Sequence (the aircraft came to rest on its left side in the valley beyond the second impact hill about 800 feet from the wheel barrier) (courtesy of AvSER, Flight Safety Foundation)



wheel barriers, cleared this with dramatic flaming of the 15 gal of residual gasoline and 40 gal of engine oil (Figs. 60 and 61), and came to rest with the cabin on its left side 860 ft from the wheel barrier (Fig. 62), 50 ft below the top of the second hill.

A preliminary attempt is made in Table 8 to reconstruct the required velocity changes of the four deceleration events. Knowing the approximate initial velocity and times and approximate distances traveled between crash events, one can compute the free flight velocities, and hence the change of velocity at each event. Then knowing the duration of the event, one can compute an equivalent mean acceleration acting for this time to produce this velocity change. Greater approximations are used in this preliminary analysis of the vertical motions. Knowing the approximate hill and impact heights and times of events, and assuming the absence of lift during free flight (supported by the floating appearance of objects in the cabin interior films), one can compute the required vertical velocity at the end of each impact event in order to stay airborne through the known time interval until the next event to reach the approximately known next impact altitude. Analytically this would be taken as $h_2 - h_1 = v_0 t - 0.5 g t^2$.

Knowing the required vertical velocity changes and impact event durations, one can then compute an equivalent mean vertical acceleration acting for this duration to produce the velocity change. Finally, in order to convert this vertical displacement acceleration (g) into a vertical accelerometer reading (G), we add the 1g of gravitation. (See Clark, Hardy and Crosbie, Ref. 44, for acceleration terminology and its history.) An improved analysis would utilize more precise hill and impact position measurements and would utilize the motion pictures for velocity measurements. It is appropriate to make this form of analysis even if all on-board recordings are obtained in order to separate out all local structural motion events.

It is emphasized again that the mean accelerations of Table 8 would probably be exceeded by peaks of a complex waveform acceleration time history recorded in the tail compartment. Fuselage collapse could lengthen impact event durations at the tail, and so reduce mean accelerations. Likewise, rotation of the tail during impact could increase, or more generally decrease, the loads in the tail compartment since deceleration durations would be increased. In the tail compartment motion pictures, for example, the wheel barrier loads appear very slight. The down loads of impact on the second hill are particularly apparent. The loads of the final impact appear rather mild, as if significant structural collapse and tail swinging occurred during this event. Indeed, the ground near the final position is not broadly furrowed (except for a drainage ditch which can be seen in Fig. 62 to continue beyond the aircraft), suggesting local loading and collapse, and the fuselage is yawed some 45° from the flight azimuth. Figures 63 and 64 show the dummy protected by the latex airbag and the comparison and side facing dummies, after wheel barrier contact, during extreme motions on the first and second hills, and during free flight before final impact. Because of the motion of the dummy with respect to the aircraft, into the air-stop restraint system, the loads on this dummy are closer to the mean accelerations of Table 8 than to the cockpit accelerometer readings of Fig. 65. Indeed,

TABLE 8
Preliminary Analysis

End of Event	Start	Wheel Barrier	Flight	First Hill	Flight	Second Hill	Flight	Valley
Ground Position	0	20	110	150	370	400	750	780 ft
Time	0	0.1	0.7	0.9	2.1	2.3	5.2	5.4 sec
V_x	235	216	216	183	183	120	120	0 ft/sec
Impact g sec		0.6		1.0		2.0		3.7
Mean G_x	0	-5.9	0	-5.1	0	-9.8	0	-18.7 G_x
Altitude	5 ^a	7	15	25	35	42	54 (peak)	-8 ft
V_z	0	23.0	3.7	27.6	4.4	27.6	-62.8	0 ft/sec
Mean G_z	1	8.1	0	4.7	0	4.6	0	10.7 G_z

^aBottom of fuselage

The positions, velocities and altitudes given represent those at the ends of the tabulated events.

NOTES:

The approximate nature of the data of this table must be stressed: i.e., we understand that the wheel barrier impact speed was about 160 mph. To the extent that the actual speed was lower than this, the deceleration loads due to the wheel barrier, which seem excessive, could be reduced.

The final impact loads into the valley also seem excessive. Close-up ground motion pictures of these events are not available. We must assume that structural collapse accounted for load attenuation in the tail compartment.

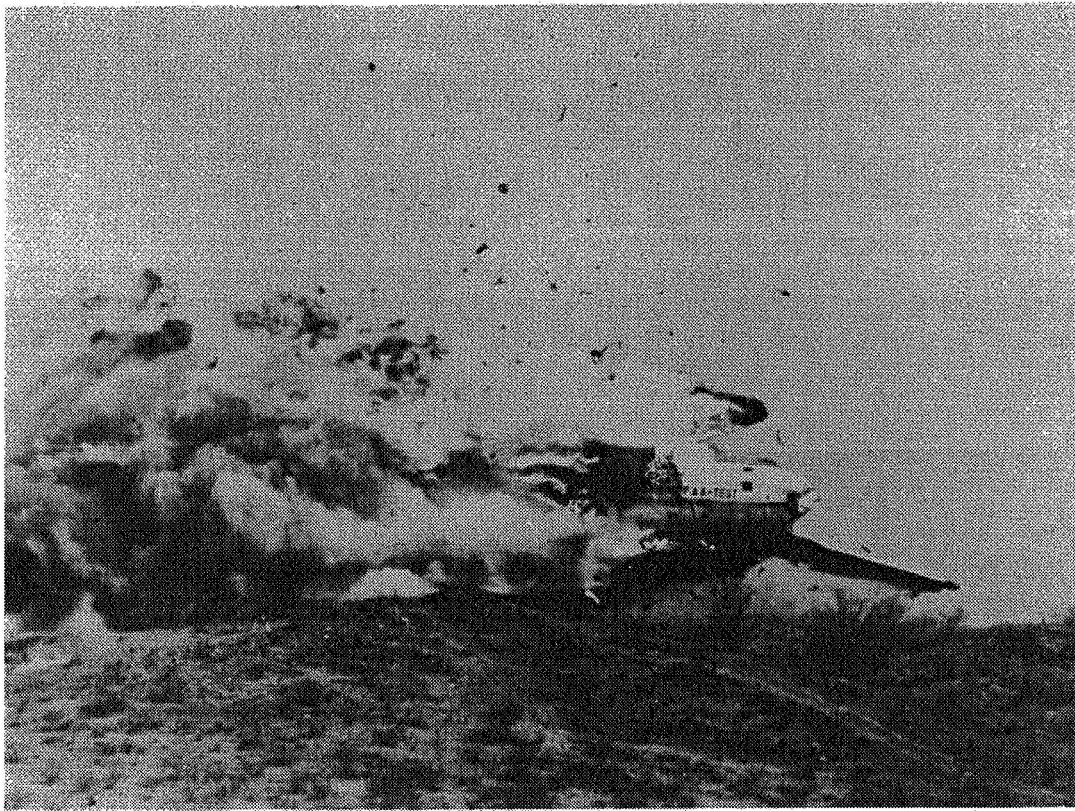


Fig. 60. The DC-7 Clearing the Second Impact Hill (courtesy of the FAA)

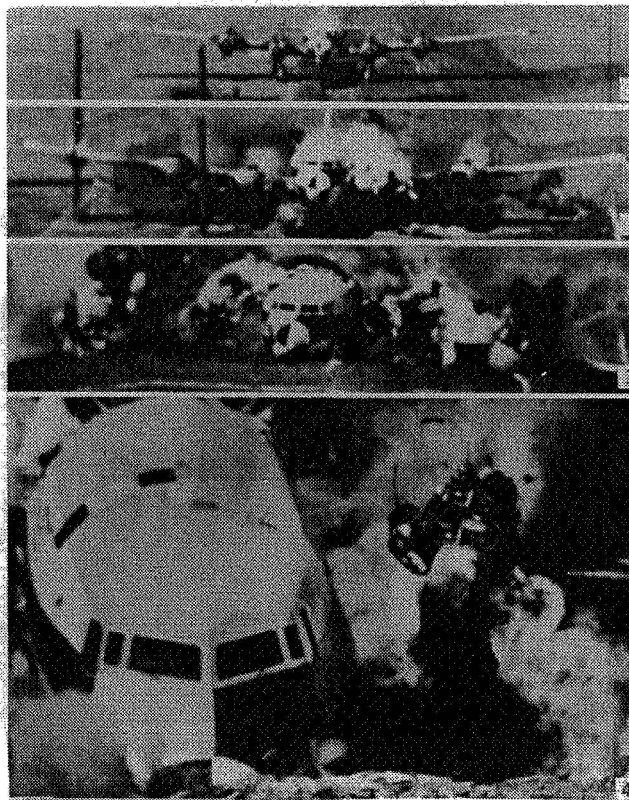


Fig. 61. FAA Crash Test at Phoenix, Arizona Showing Head-on View of the Aircraft as it Strikes the Barriers and Hills

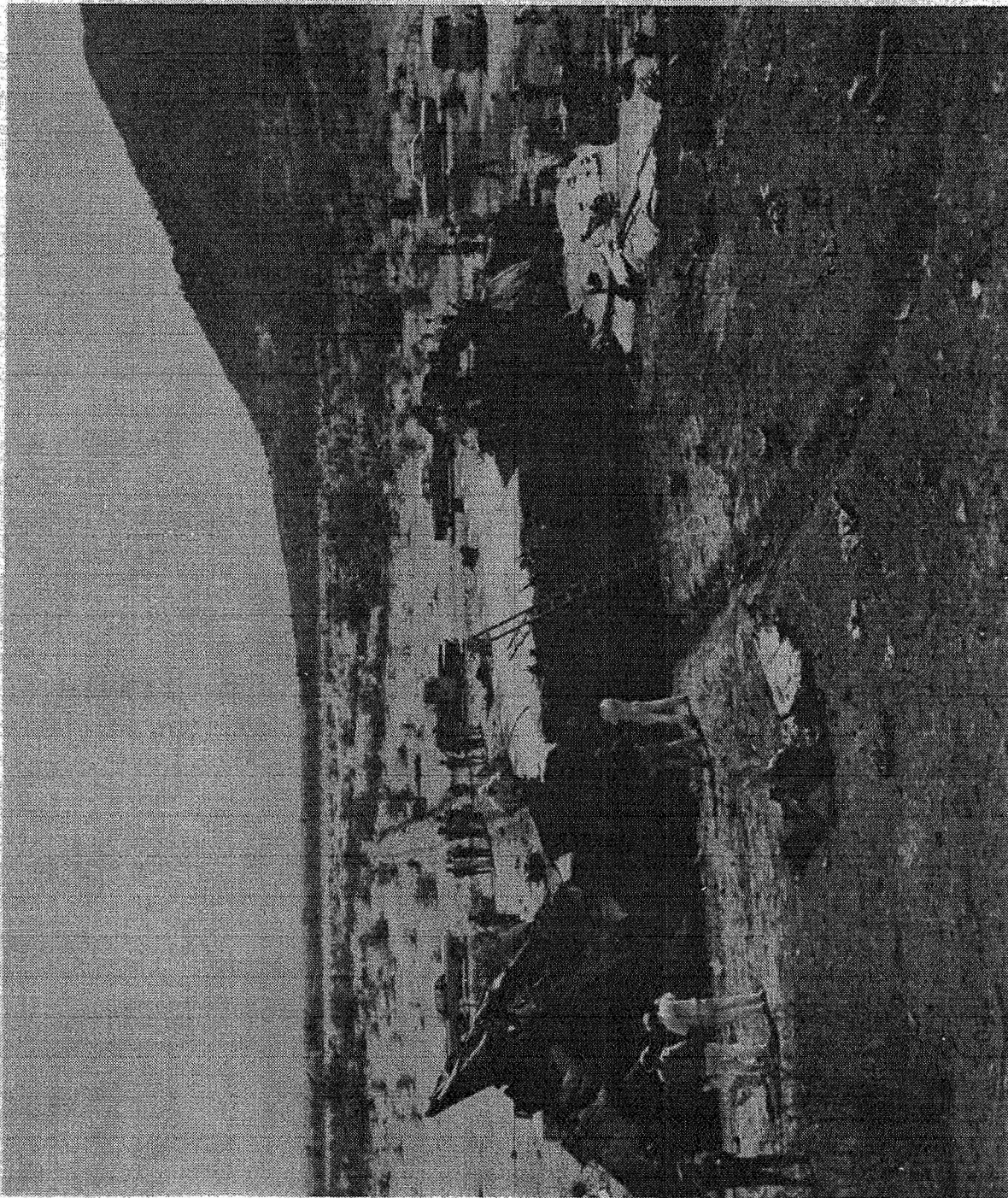


Fig. 62. The DC-7 Showing the Final Resting Position

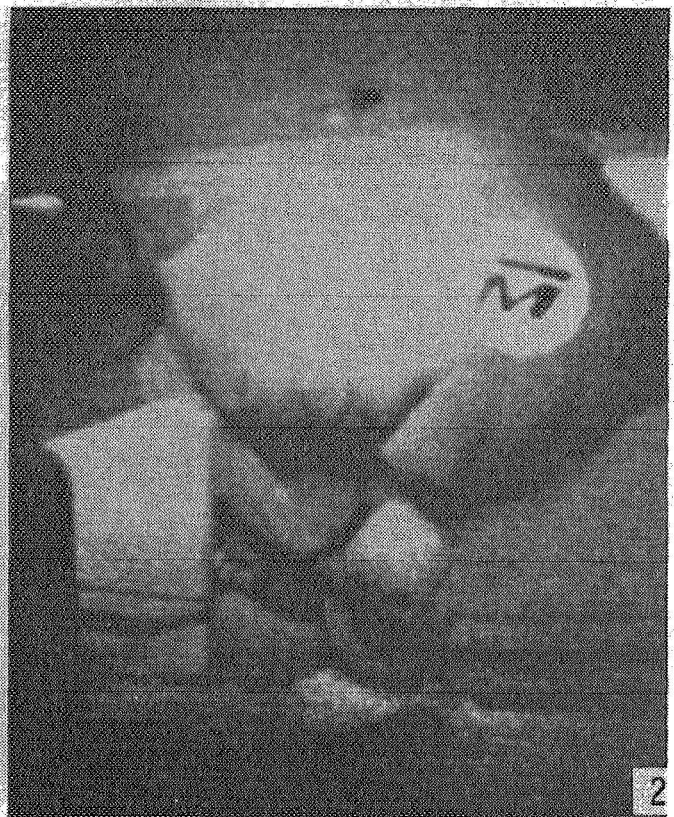
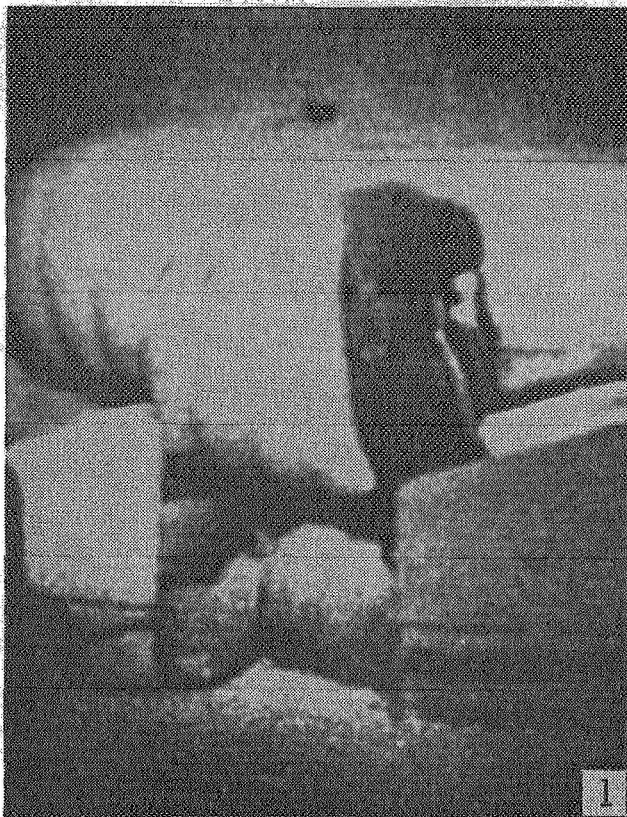


Fig. 63. Airstop Dummy During the DC-7 Crash from Motion Pictures (courtesy of the U.S. Army)

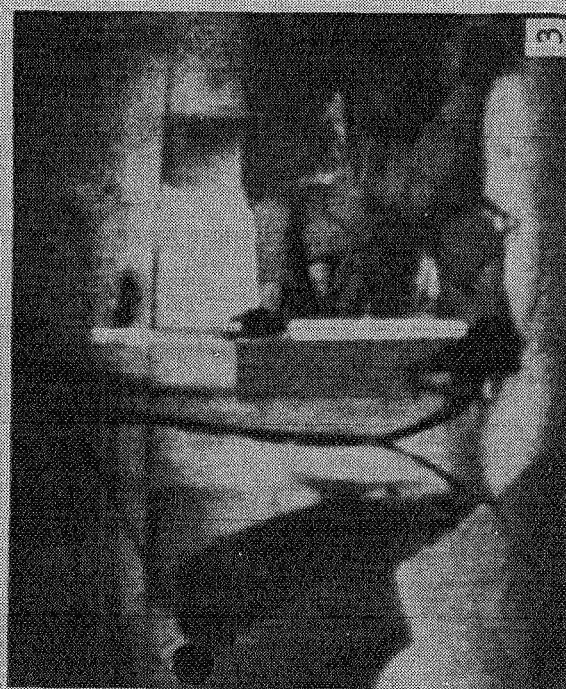
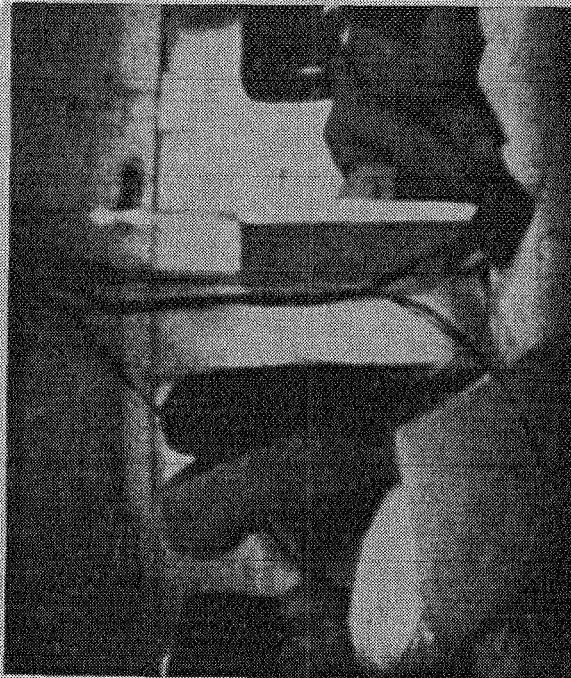


Fig. 64. Comparison Dummy During the DC-7 Crash from Motlon Pictures (courtesy of the U.S. Army)

to the extent that there is significant fuselage collapse, the loads on the airstop dummy can be lower than the mean accelerations of Table 9, to the extent that

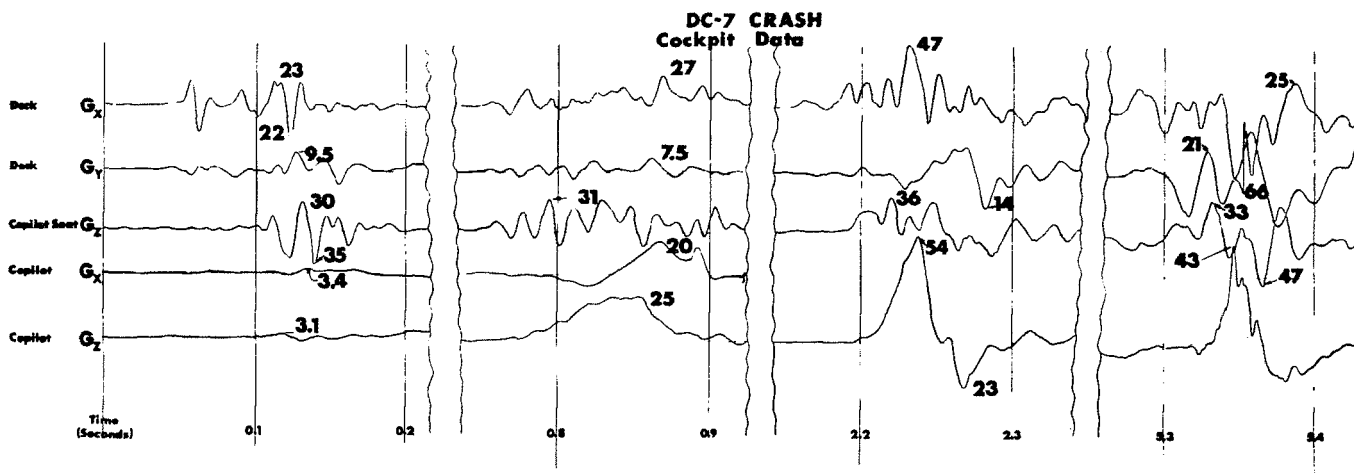


Fig. 65. Acceleration Time History in the Cockpit During the DC-7 Crash

the collapse lengthens the impact duration. In making a preliminary comparison of the dummy motion into the airbags during the crash from the motion pictures to dummy motion into airbags in which we have accelerometer readings, we suggest that the dummy received on the first hill a longitudinal chest load of about $-8G_x$ and a vertical chest load of about $5G_z$, on the second hill $-5G_x$ and $10G_z$, and on the valley floor $-3G_x$ and $5G_z$, followed by perhaps $3G_y$ as the aircraft yawed then came to rest on its left side ($+1G_y$). However approximate these estimations, the appearance of the dummy during and after the crash was that it would not have experienced significant (if any) injury (see Fig. 66).

We were surprised to see a significant part of the vertical load isolation provided by the foot bags, for the dummy went forward and down onto these with his knees during the hill impacts. The major down loads of this crash re-emphasized for us the need for a controlled yielding material below the passenger as well as in front of him.

It can be seen in picture 2 of Fig. 63 that the first hill impact causes the seat in front to fold forward. Without a chest bag in this seat, in front, the back remained forward, causing the dummy chest bag, attached to this back, to be higher up on the chest than intended, although adequate support was provided. In addition, the use of the slack seat belt allowed the dummy to float up during the $0G_z$ flight after the second hill (picture 4, Fig. 63), opening up the restraint far more than would be desired. On hitting the valley floor, the head

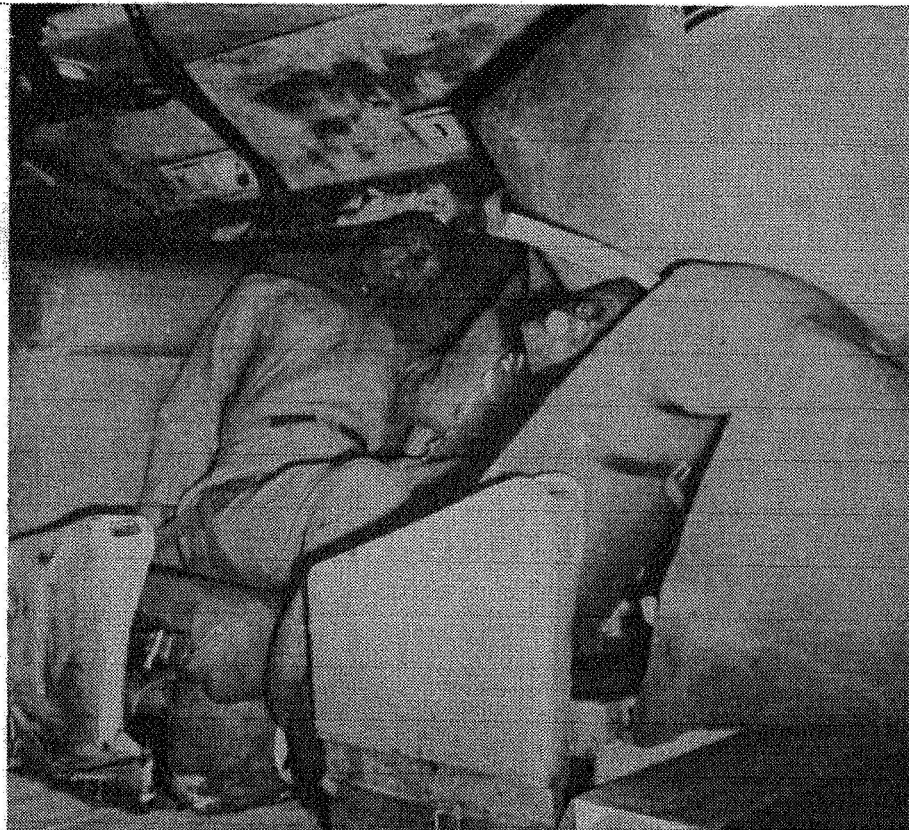


Fig. 66. Airstop Dummy After the DC-7 Crash. Note: Aircraft Is on Left Side (courtesy of the FAA)



Fig. 67. Airstop Dummy After the DC-7 Crash. Note: Aircraft Is on Left Side. Also Note Position of the Dummy Protected by the Vinyl Chloride Airbag (courtesy of the FAA)

did have room to swing forward before hitting the airbag. Nonetheless, if the head hit a yielding material one might have a headache from this slap but not a concussion. With the full airstop system (including airseat) at each position, one can have a tight lap belt yet obtain load isolation and the restraint does not open up at 0G.

The accelerations of the dummy behind the polyvinyl chloride transparent chest bag cannot be estimated. From the film, there is a suggestion that this bag is still inflated after the first hill, but the latex bag and dummy generally obscure the window seat dummy. The vinyl bag was torn after the crash, but the dummy was still in the seat and in apparently good condition, although its body and head were tipped forward onto the seat in front, which did not fail (Fig. 67).

The comparison dummy (Fig. 64) experienced the typical jack-knifing about the lap belt on severe impact, breaking off its head on the seat in front, a head load expectedly more than $-40G_x$. Note also in Fig. 64 the severe deformation of the seat, to which the belt snap or bottoming loads contributed. The seat belt of the side facing dummy broke on the second hill. Figure 68 shows the comparison dummy on the right after the crash, still in its seat but headless. The side facing dummy was thrown across the aisle. The feet on the left are for a third dummy.

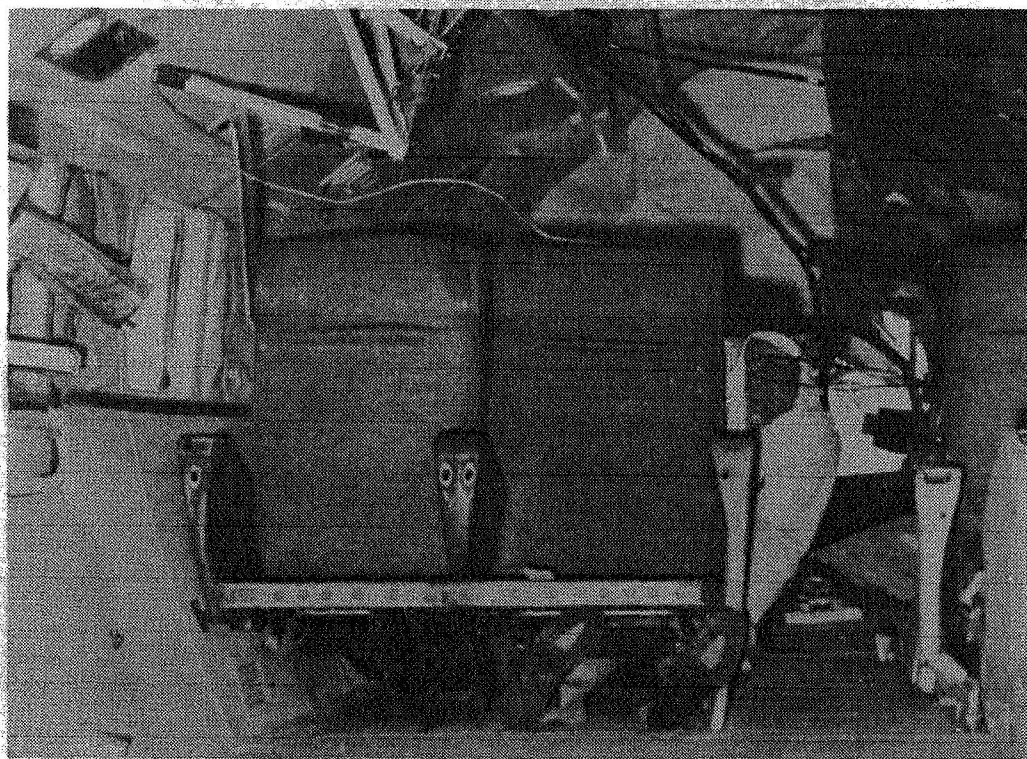


Fig. 68. Comparison Dummy After the DC-7 Crash. Looking Aft, Note Displacement Under Seat and Missing Head of the Aisle Dummy



Fig. 69. Airseat



Fig. 70. Airseat Deflated to Aid Rapid Aircraft Evacuation

D. THE AIRSEAT DESIGN AND SWING AND DROP TEST

Other experiment priorities for the second planned FAA experiment precluded the addition of the airbag restraint system. However, the U.S. Army had planned a series of crashes and we shifted our systems to these tests. In examining the down loads associated with a crash, we wanted to provide impact isolation in the vertical as well as the longitudinal direction. A second addendum to the contract in July 1964 added this aspect to the complete system. (This addendum also covered the development and tests of the "airlitter" system.)

To provide isolation from the severe down loads of crashes, to reduce the rebound loads when hitting the seat, and to significantly improve the ease of rapid escape from the aircraft after a crash, we began the development of an inflated seat structure we call "airseat" (Fig. 69) which will look, feel, and operate like present seats under 1G conditions. The airseat will provide controlled yielding, without metal failure, under crash conditions for vertical load isolation, and most significantly can be deflated after the crash (Fig. 70) so that not only are the airbags out of the way but all the seats as well are collapsed onto the floor, opening up the entire cabin as an escape corridor.

Swing impacts of the complete airstop system, with airseat (Fig. 71) show that this does indeed provide improved crash isolation over the airbags alone,

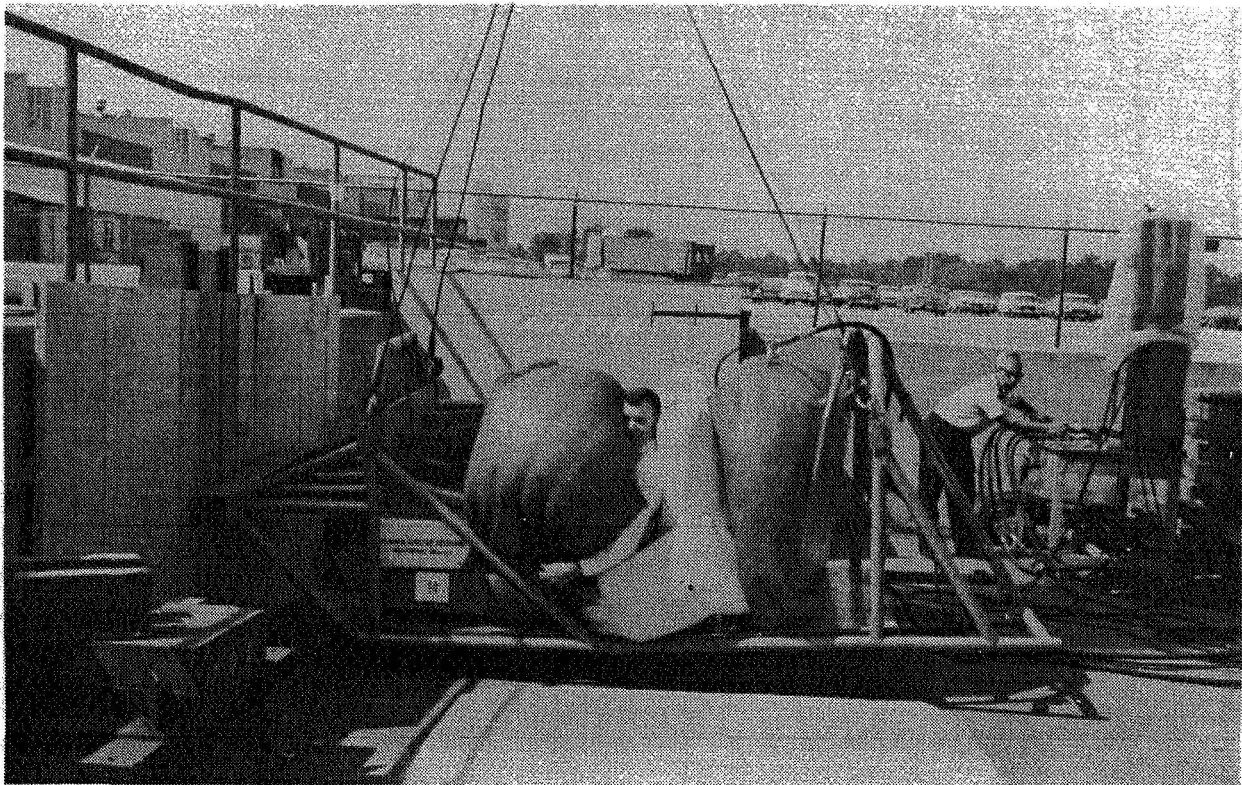


Fig. 71. Swing Impact of the Complete Airstop System (with airseat) (impact velocity 16 ft/sec, human subject)

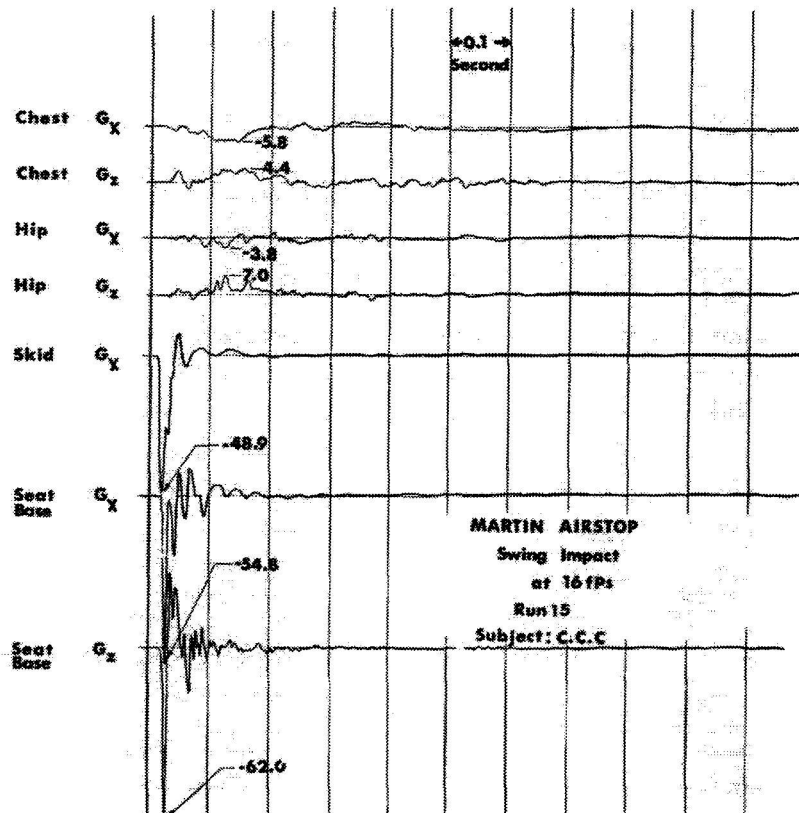


Fig. 72. Acceleration Time History of a Swing Impact of the Complete Airstop System (impact velocity 16 ft/sec, human subject)

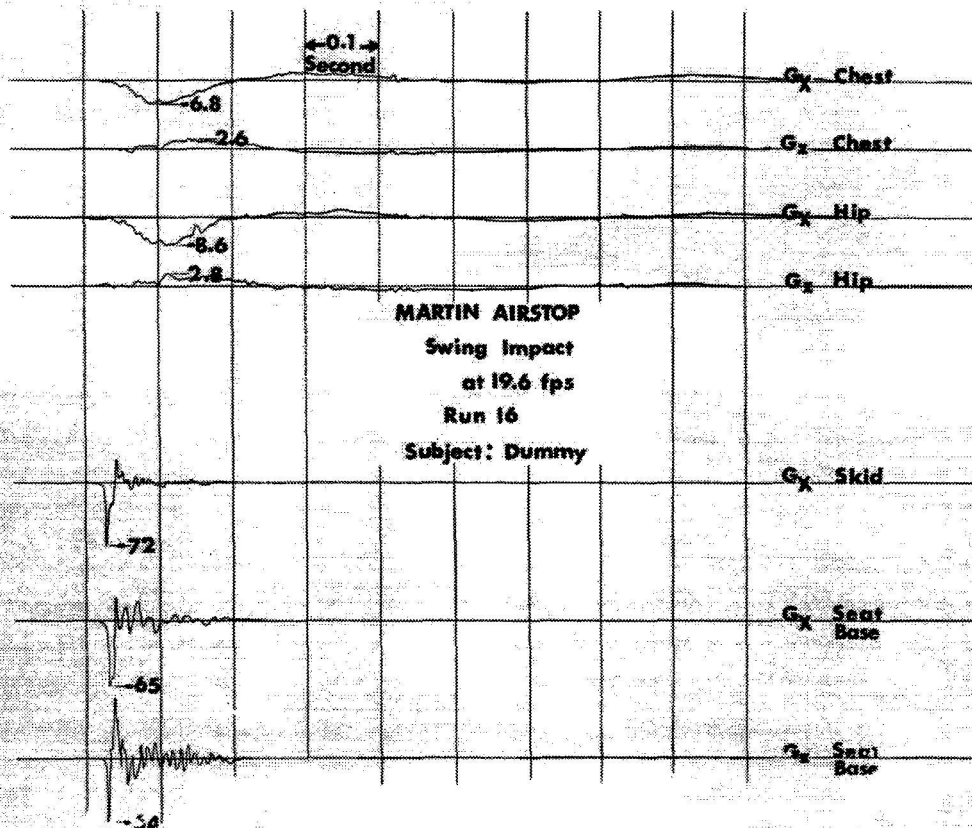


Fig. 73. Acceleration Time History of a Swing Impact of the Complete Airstop System (impact velocity 19.6 ft/sec, dummy subject)

with significantly reduced rebound and vertical loads (Figs. 72 and 73) experienced by the subject. In these tests, the swing rig loads are higher than the swing rig loads of Figs. 47 and 48, although the impact velocities are the same. A 6-in. polyurethane foam bumper of the first series was replaced by a metal paint can collapse for this series. However, it is the velocity change rather than the swing acceleration which determines the energy to be dissipated by dummy motion, so that these runs are comparable.

Note in Fig. 71 that the airseat deforms forward and down, staying with the back of the body. This helps reduce the rebound load. Moreover, if a lap belt were worn attached to the airseat at seat level but not to the floor, the belt would not transmit bottoming loads to the subject. Hence, the belt could be worn to provide turbulence restraint when the chest and foot airbags are not in use and to hold the subject in the restraint during $0G_z$ or $-G_z$ phases of the crash without jeopardizing the load isolation qualities of the system.

One would not elect to make a 16-ft drop in any present aircraft seat, but with the airstop restraint, with airseat (Figs. 74 and 75), the loads of even this condition are tolerable (Fig. 76). As with the astronaut airbag restraint, note that the secondary impact of the skid when it slams down to level attitude has minor effect on the subject; airbag restraints provide excellent multiple impact protection.

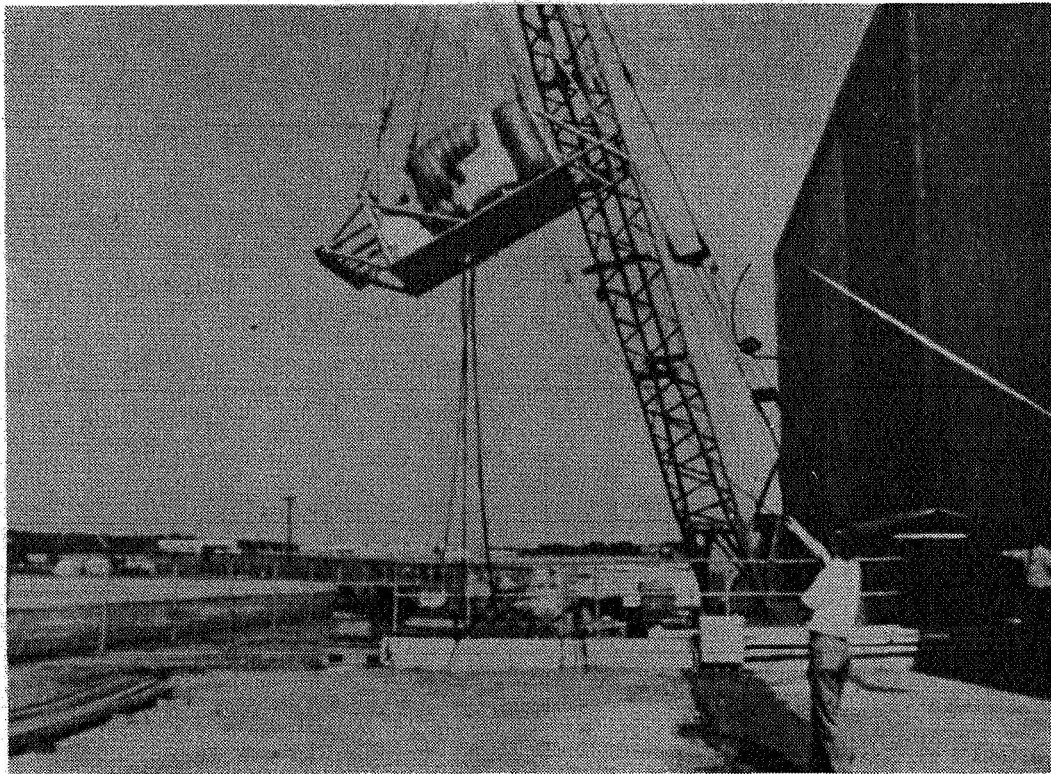


Fig. 74. Crane Drop of the Complete Airstop System, with Airseat, 30° Nose Down Attitude (impact velocity 32 ft/sec, dummy subject)

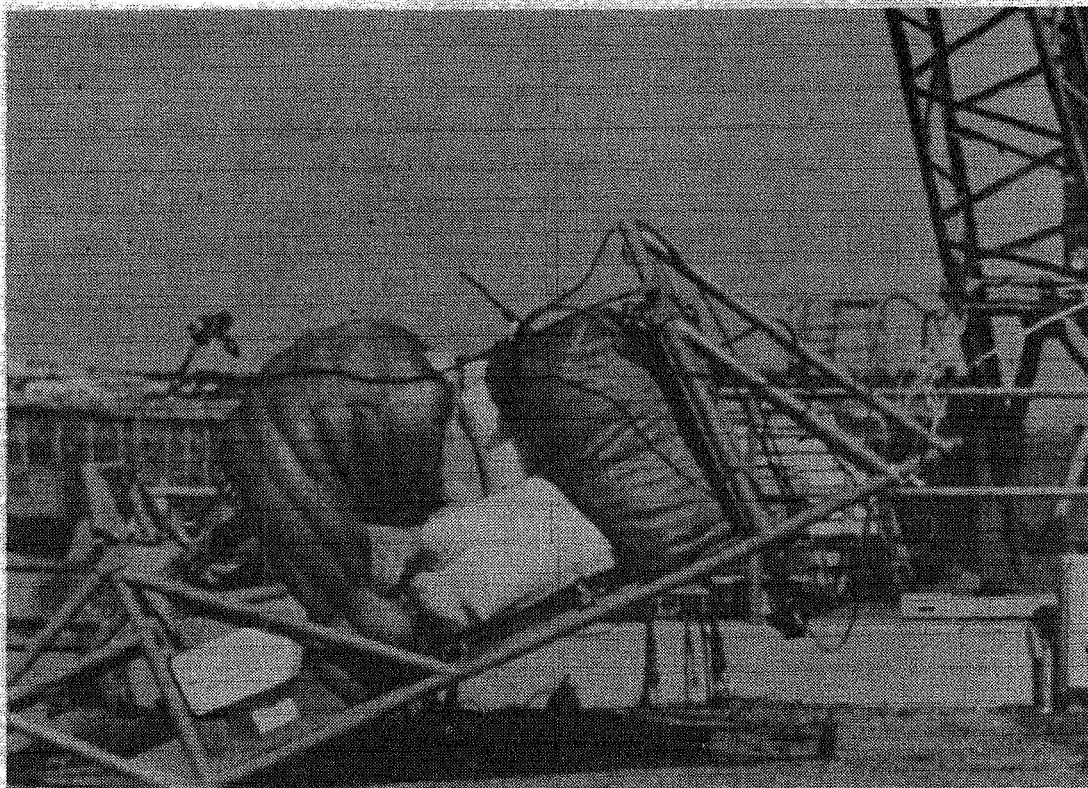


Fig. 75. Crane Drop of the Complete Airstop System During Impact (impact velocity 32 ft/sec, dummy subject)

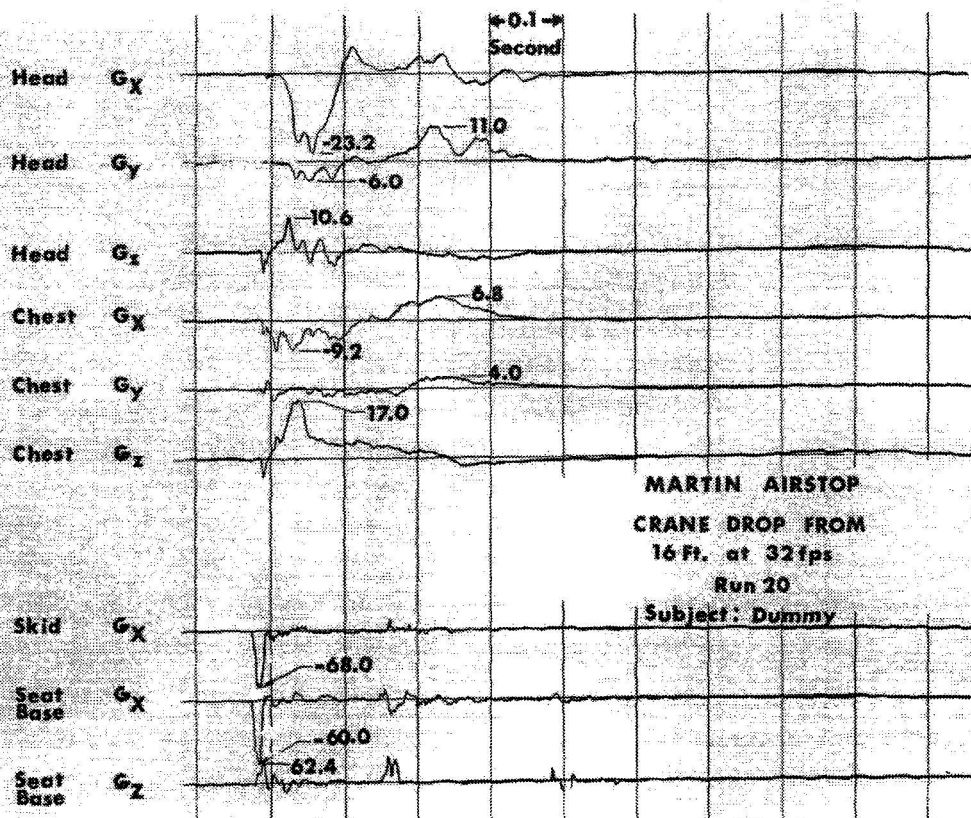


Fig. 76. Acceleration Time History of the Crane Drop of the Complete Airstop System, 30° Nose Down Attitude (impact velocity 32 ft/sec, dummy subject)

The rebound condition of this 16-ft drop involved considerable dummy motion as the seat tipped back. Although a bag was provided in back of the airseat (Fig. 75), it is expected that a full system, with multiple airstop seats, would have provided less rebound.

Table 9 presents the pertinent data from this series of experiments.

TABLE 9
Airstop Test Data Restraint System--Swing Impact

Run No.	Impact Velocity (fps)	Impact Medium	Subject Accelerations									Seat Base Accelerations	
			G _x			G _z			G _y			E _x	E _z
			Head	Chest	Hip	Head	Chest	Hip	Head	Chest	Hip		
1	9.8	Steel on wood	-3.4	-4.0	-6.0	-2.0	+2.3	+4.0	-2.3	-	-2.1	-40	-33
2	11.3	Wood on wood	-5.0	-6.1	-6.2	+2.0	+2.7	+4.2	+4.0	-	-1.9	-25	-15
3	13.9	Wood on wood	-5.5	-5.5	-5.9	+3.7	+3.9	+5.4	+6.3	+1.8	+2.7	-25	-21
4	13.9	Wood on wood	-6.6	-4.8	-7.5	+3.5	+2.3	+5.2	+3.0	-	+4.6	-23	-22
5	16.0	Wood on wood	-5.2	-6.7	-8.5	+5.5	+3.5	+6.2	+4.8	-	+2.5	-31	-33
6	16.0	Wood on wood	-5.0	-8.9	-7.7	+3.9	+3.9	+6.0	+7.4	+2.5	-	-(32)	-
7	16.0	1 crush cyl	-2.8	-5.6	-7.8	+4.1	+2.9	+3.4	+3.2	-	-	-(43)	-30
8	19.6	2 crush cyl	-4.6	+6.3	-13.2	+5.3	+6.3	+4.2	-5.3	+1.8	-5.3	-(37)	-37
9	19.6	1 crush cyl	-4.2	-6.4	-7.4	+3.6	+3.8	+5.8	-3.4	-2.6	-3.4	-75	-37
10	19.6	1 crush cyl	-7.6	-6.6	-8.4	+4.2	+3.8	+7.4	-9.2	-6.2	+14.6	-66	-62
11	19.6	1 crush cyl	-4.8	-5.0	-9.0	+3.4	+2.4	+4.0	-2.8	-2.2	+2.2	-57	-56
12*	11.3	1 crush cyl	-	-2.8	-	-	+3.0	-	-	-	-	-21	-11
13*	16.0	1 crush cyl	-	-6.6	-	-	+7.4	-	-	-	-	-54	-59
14*	16.0	1 crush cyl	-	-6.8	-3.8	-	+4.2	+3.0	-	-	-	-51	-62
15*	16.0	1 crush cyl	-	-5.8	-3.8	-	+4.4	+7.0	-	-	-	-55	-62
16	19.6	1 crush cyl	-8.2	-6.8	-8.6	+3.8	+2.6	+2.8	-3.6	-3.2	-3.4	-65	-64
17	19.6	4 crush cyl	-8.8	-8.4	-8.6	+3.6	+2.6	+3.6	-2.6	-1.8	-2.2	-59	-58
18	19.6	4 crush cyl	-9.0	-7.6	-7.6	+2.6	+2.6	+3.8	-5.4	-2.4	-2.4	-48	-31
Vertical drop at 30° nose down attitude													
19	17.9	Steel on asphalt	-10.2	-4.6	-6.6	+9.4	+7.8	+6.8	-2.6	-2.4	-2.8	-22	-28
20	32.0	Steel on asphalt	-23.2	-9.2	-19.4	+10.6	+17.0	+18.0	+11.0	+4.0	+11.4	-60	-62

*Manned Tests by C. Blechschmidt (Runs 12 and 13) and C. Clark (Runs 14 and 15).

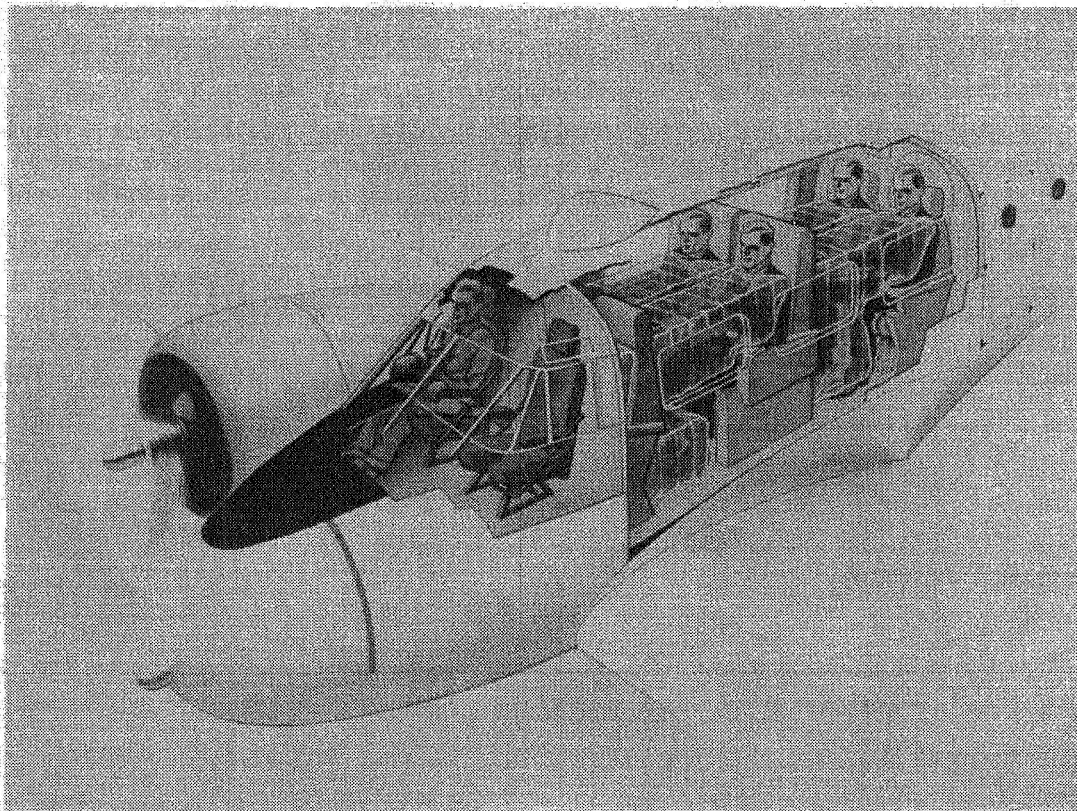


Fig. 77. Airstop Arrangement for the C-45 Crash Test of November 1964

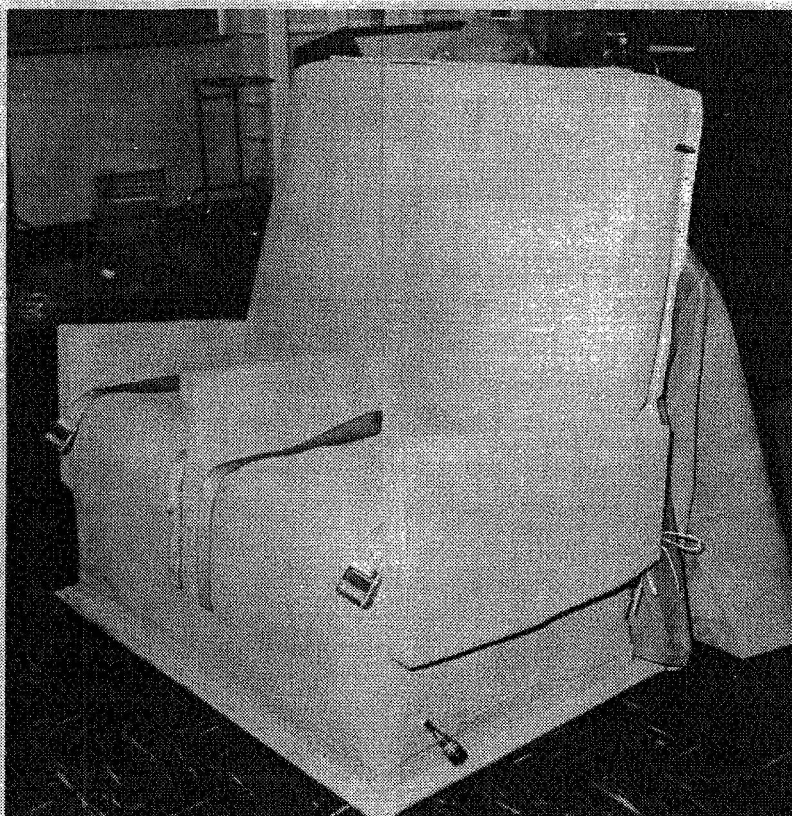


Fig. 78. The Airseat Used in the C-45 Crash Test of November 1964

E. THE C-45 CRASH TEST OF NOVEMBER 1964

On November 6, 1964, a C-45 was experimentally crashed in Phoenix, Arizona, by the AvSER (Aviation Safety Engineering and Research) group of the Flight Safety Foundation under the direction of the U.S. Army. An artist's concept of this experiment is given in Fig. 77. Figure 78 shows the airseat prior to installation.

Figure 79 shows the interior of the test aircraft cabin as viewed from the cockpit. First are the airbags between the bulkhead and the unoccupied front seats, then the latex and the 5-mil elastomeric vinyl chest airbags for the two anthropomorphic dummies on the airseat, then the airbags in front of the two dummies seated in the rear conventional airplane double seat.

The two airseat dummies were secured to the airseat with lap belts. The left rear dummy had a tight lap belt and the right rear dummy had no lap belt.

The aircraft was guided on a track similar to that employed on the DC-7 test, and positioned in a flying level attitude by a tail support (Fig. 80).

The plane was accelerated under its own power down the guide track to a speed of 100 mph, then the landing gear and the track guide system were broken free by impact with a prepared barrier. The aircraft then flew into prepared barriers to simulate wing low and tree impacts with the wings. The fuselage then impacted a 30° sloping hill 15 ft in height, bounced over the top (Fig. 81), and came to rest on the far side of the hill having traveled only about twice its length from the point of nose impact. Figure 82 shows the final position of the aircraft.

Figure 83 shows the cockpit after the crash. The dummy pilot's head, missing in the photograph, was found 58 ft forward of the aircraft. A small cockpit fire was rapidly put out. Note that the co-pilot's shoulder straps failed (Fig. 83).

Figure 84 is taken from the right outside of the aircraft after the crash showing the dummy in the right-hand side of the airseat still strapped in the now deflated airseat in its initial position.

The left rear dummy (strapped to the conventional seat) in his forward travel at impact took the whole seat and floor seat attachment with him. He was still in his seat with the tight lap belt, but wound up on his knees with head facing forward and displaced forward to a position about where the airseat was attached. The right rear dummy was free from the seat at impact and wound up on top of the left-hand airseat dummy (Fig. 85).

The left airseat dummy was still strapped to the airseat but moved forward and was under the right-hand rear dummy. The right airseat dummy was in its initial position kneeling on an inflated underseat bag and still strapped to the deflated airseat (Fig. 86).

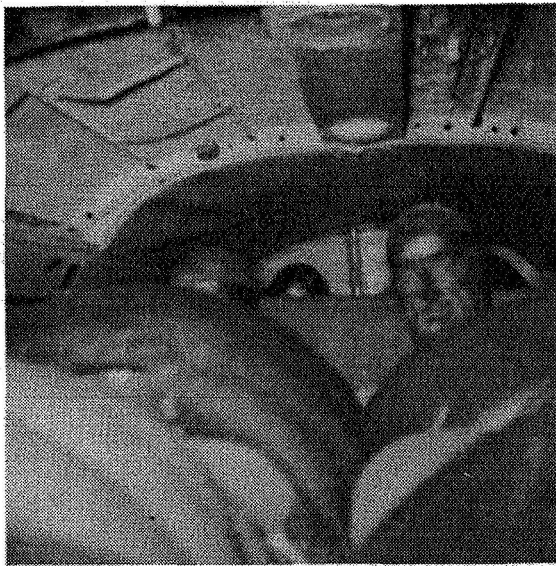


Fig. 79. Airstop Installation for the C-45 Crash Test of November 1964, Looking Aft From Cockpit Showing in Foreground the Dummies in the Airseat

Fig. 80. Rail Guidance System and Tail Support
--C-45 Crash Test of November 1964

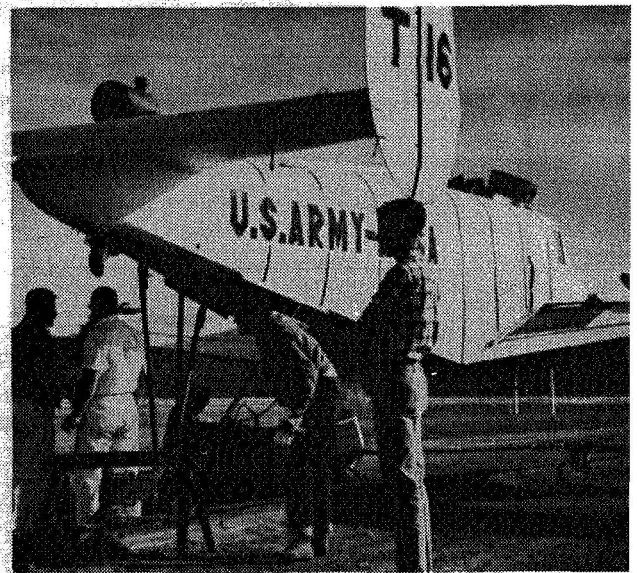


Fig. 81. C-45 Crash Test of November 1964.
Aircraft Shown as it Bounced over
the Impact Hill

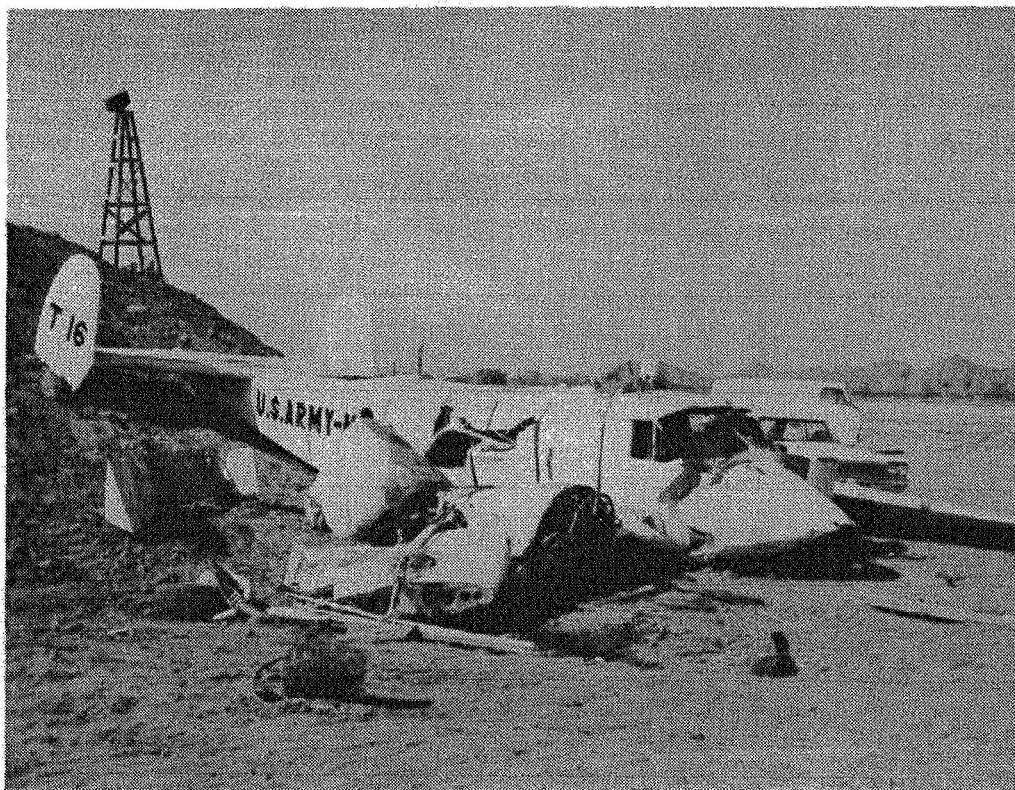


Fig. 82. C-45 Crash Test of November 1964. Final Position of Aircraft on Far Side of Impact Hill



Fig. 83. C-45 Crash Test of November 1964. View of Cockpit After the Crash

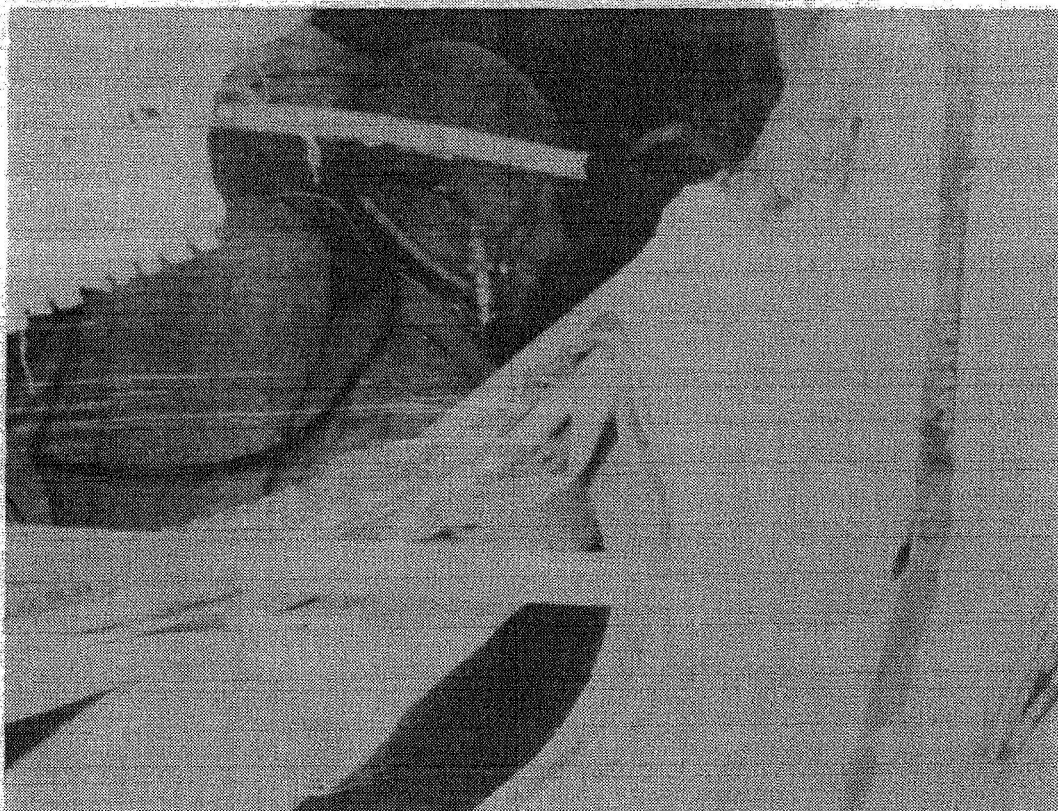


Fig. 84. C-45 Crash Test of November 1964. Looking Through a Tear in the Right Hand Side of the Fuselage After Impact Showing the Right Airseat Dummy Still in Place



Fig. 85. C-45 Crash Test of November 1964, Interior View Looking Forward After Removal of the Torn-Free Rear Seat

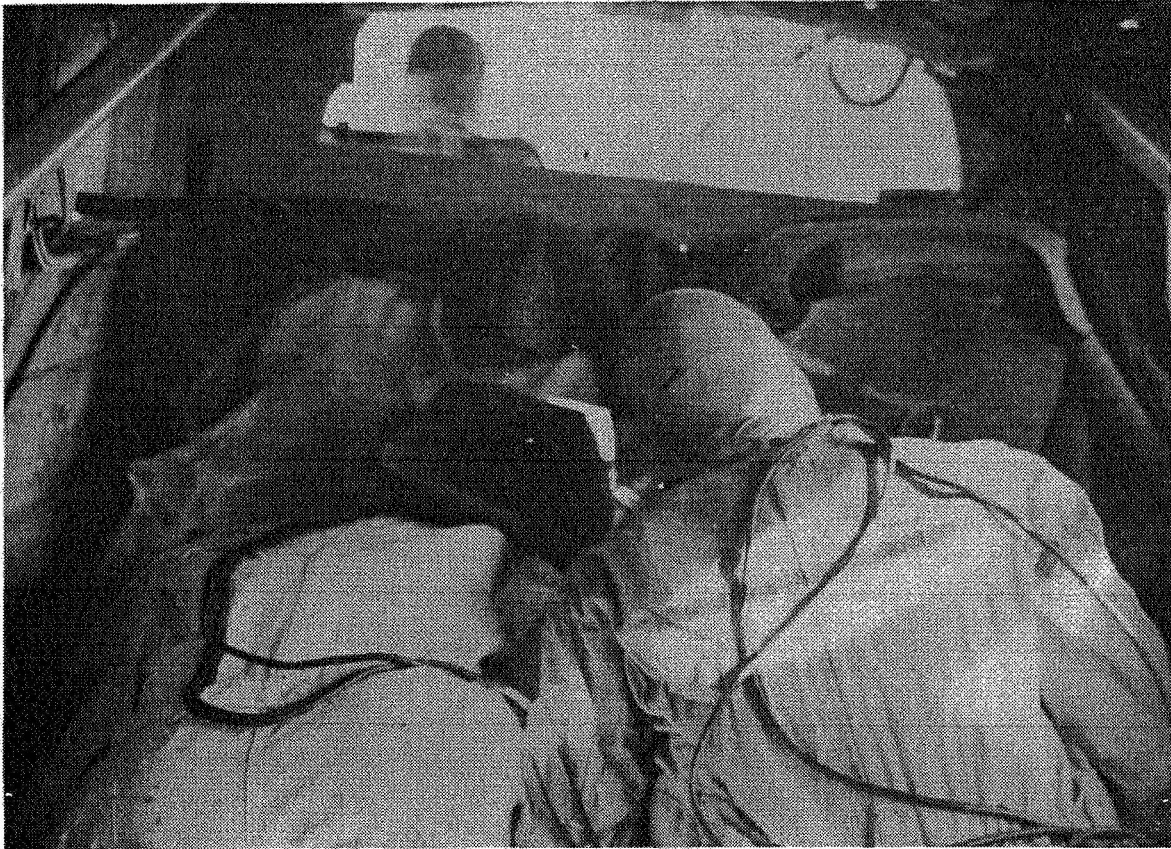


Fig. 86. C-45 Crash Test of November 1964, Interior View Looking Forward Shows the Airseated Dummies After Removal of the Rear Dummies and Torn-Free Rear Seat

Even though the chest airbags failed during the crash event, the motion pictures (Fig. 87) show the airseated dummies do return to their normal position after the primary impact. The films show the rear seat chest airbags failing on the first impact. The chest airbags of the airseat dummies must have failed later. If all the seats in this aircraft had been of conventional design, they and their dummies after the crash would have been stacked against the forward bulkhead.

The triggering system for automatic deflation of an airbag was demonstrated on this crash test. The left front airbag between the cockpit bulkhead and the left front seat was connected to an automatic dump system attached to the left wing. An acceleration sensitive switch triggered a 12 sec delayed automatic dump valve. Flash bulbs seen firing in the motion pictures indicated the initiation of the 12 sec delay and the opening of the dump valve. The automatic dump system would have worked had the airbag not broken on impact.

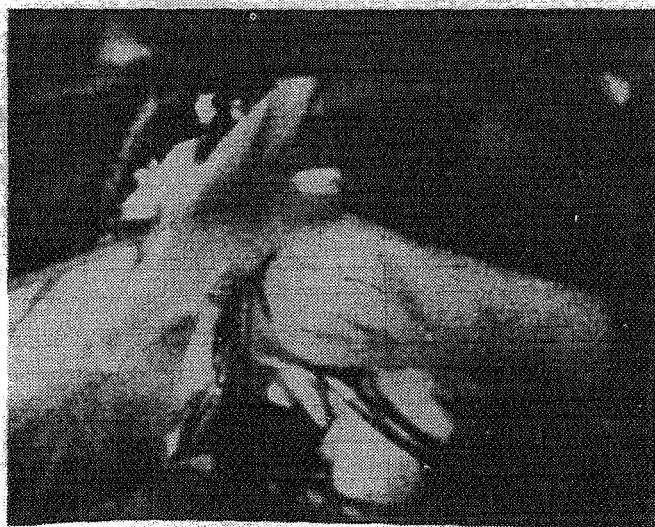
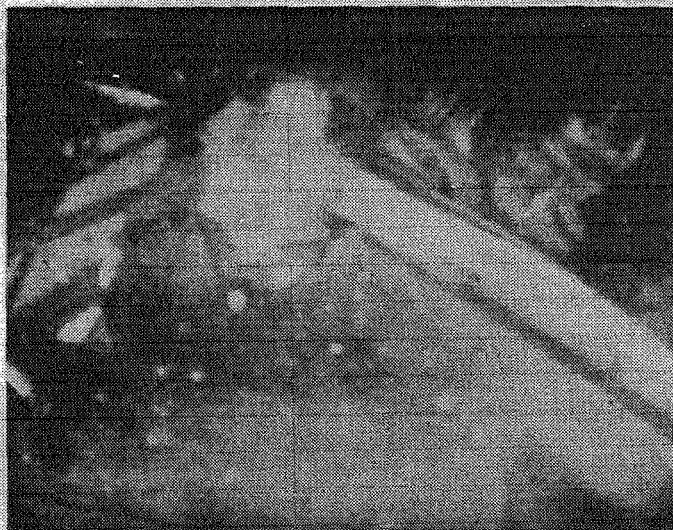
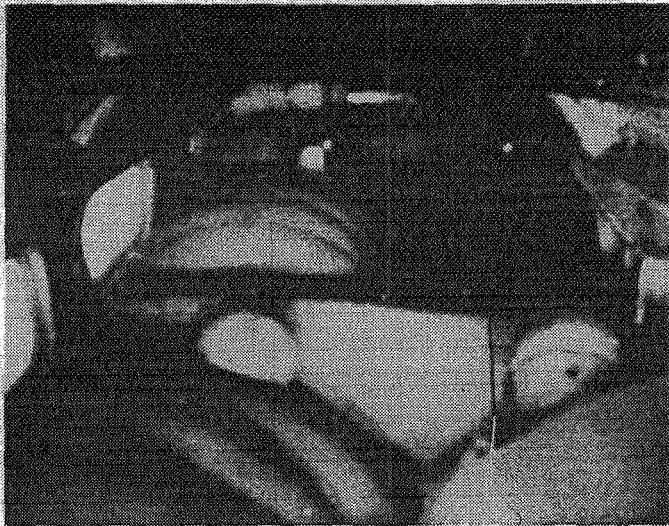


Fig. 87. C-45 Crash Test of November 1964. From Motion Pictures Looking Aft in Aircraft: 1. At Start of Impact Event; 2. Right-Hand Rear Seat Dummy and Torn-Free Seat Moving Up and Over Airseat; 3. Return to Near Normal Position After Initial Impact; 4. Position of Aft Seat over Airseat at Final Position

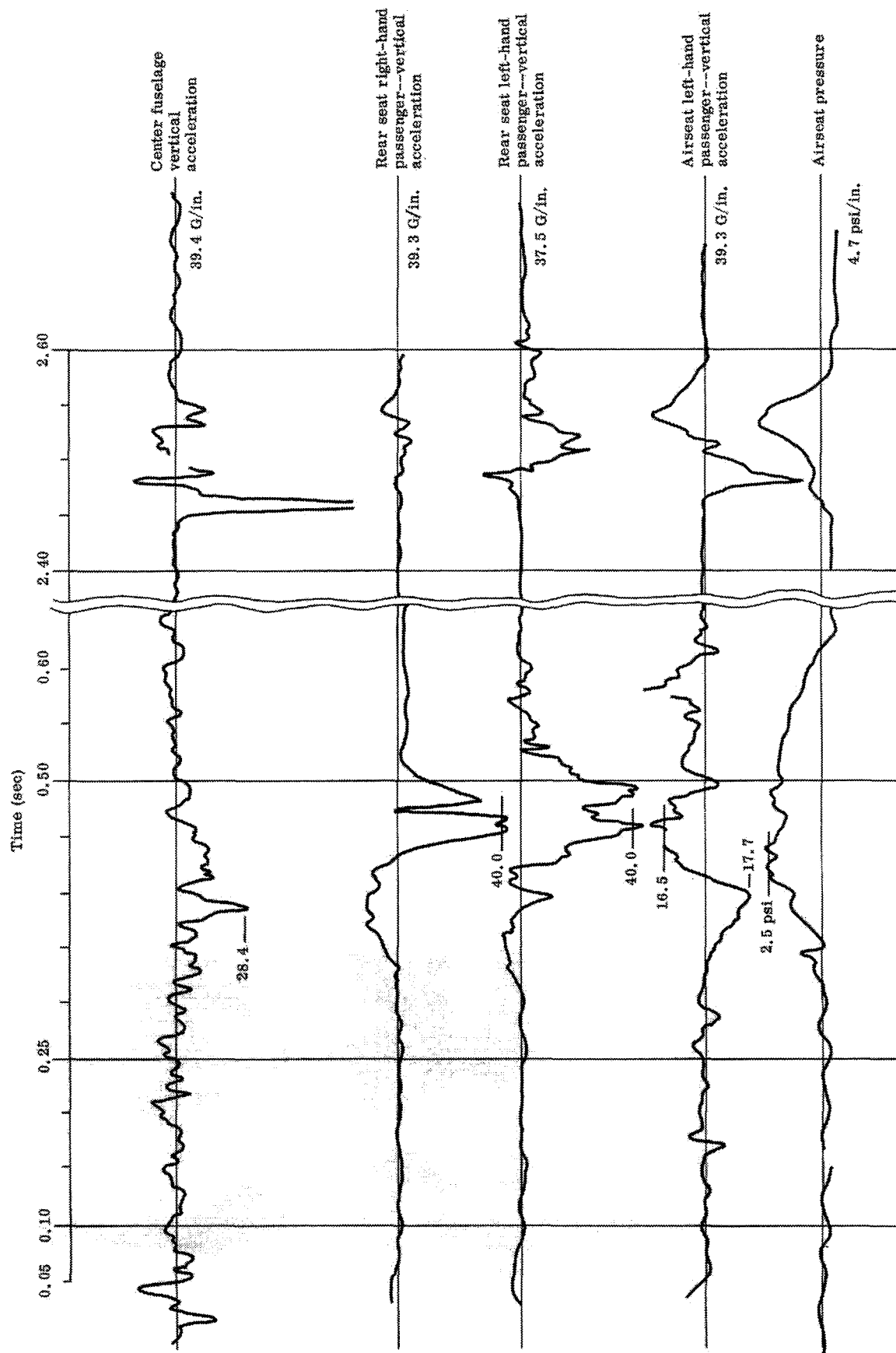


Fig. 88. C-45 Crash Test of November 1964, Time History Accelerations Comparing Vertical Loads, Airseat Effectiveness

The data obtained and presented here and in Appendix A are not readily usable and are interpreted as having detection or transmission artifacts. Because the rear seat dummies do come free, the amount of data interpretation and cross referencing to the motion pictures would be excessive. One example, however, is shown in Fig. 88 where we compare the vertical isolation properties of the airseat at the first impact; a valid comparison if the rear seat had not yet come free. Note the dummies in the rear standard seat receive a load of $40 G_z$ while the airseated dummy, because of the controlled isolation properties of the airseat, receives a maximum of $17.7 G_z$. It is readily apparent that a controlled isolation device, such as the airseat, has applications in helicopters and VSTOL aircraft for crash protection. In the aircraft use of an airseat it is recognized that ejection in the seat in the conventional manner is not possible because of the bottoming loads involved. This problem could be resolved by utilizing a rigid lock-up device such as very high pressure into the seat of limited distention or by employing the "Yankee" tractor rocket ejection system (Stanley Aviation Co.).

F. THE C-45 CRASH TEST OF APRIL 1965

To examine the rearward facing load isolation aspects of an airseat without the upper body chest airbag, a third addendum in February 1965 provided for the system to be tested in another planned U. S. Army experimental crash.

The aircraft and impact hill configuration for this experimental crash was the same as that for the C-45 crash test of November 1964 (Fig. 89).

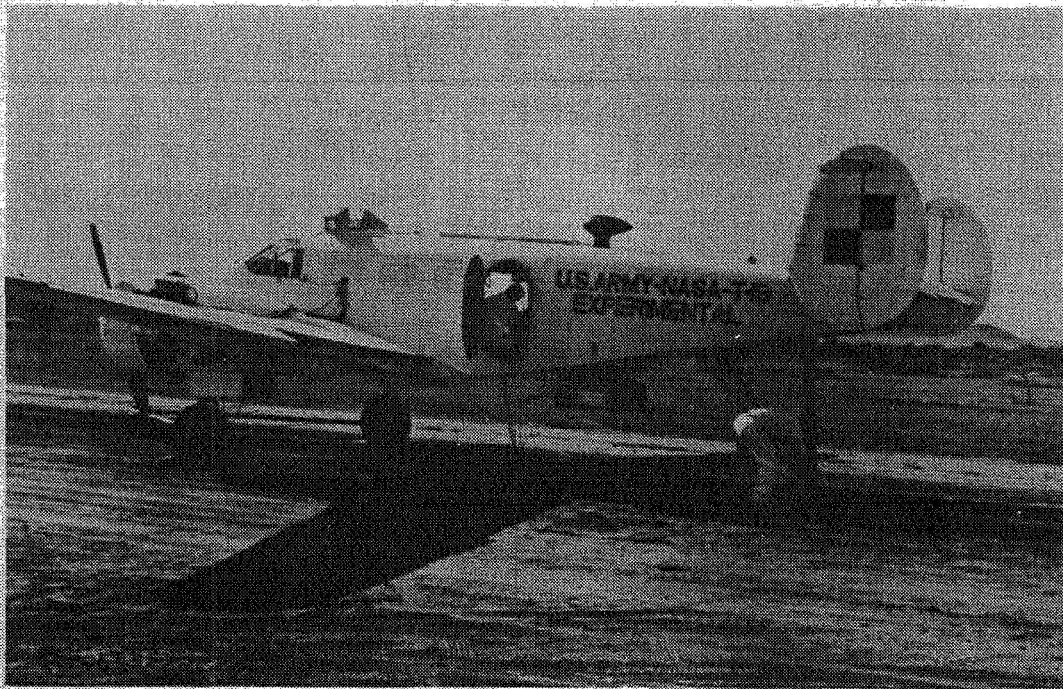


Fig. 89. C-45 Crash Test of April 1965, Aircraft Positioned in Flying Attitude on Guidance Rail

In this second C-45 crash, a single passenger airseat in a rearward facing configuration without the chest or foot airbags was positioned near the cockpit bulkhead (Fig. 90).

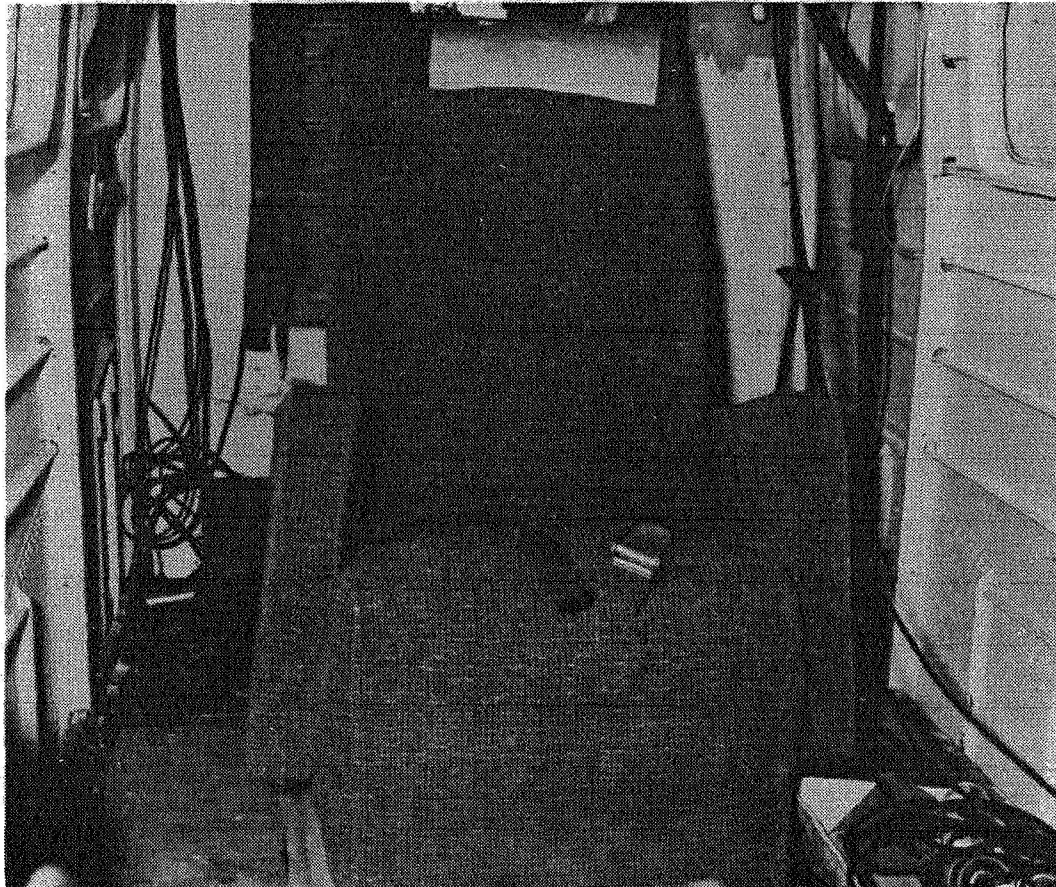
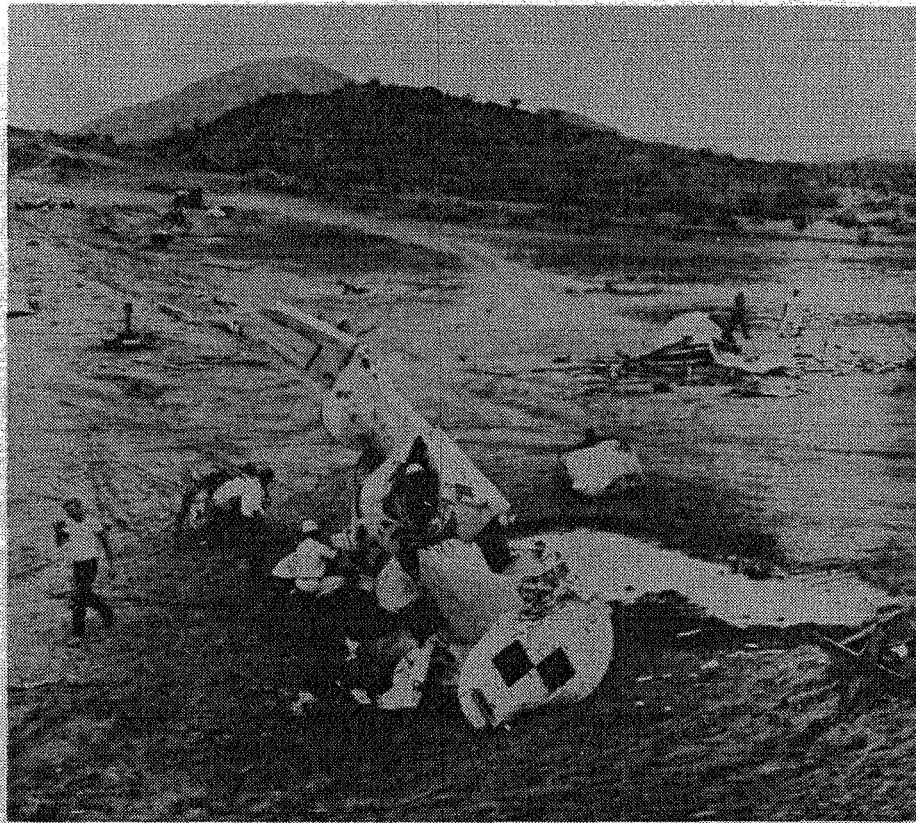


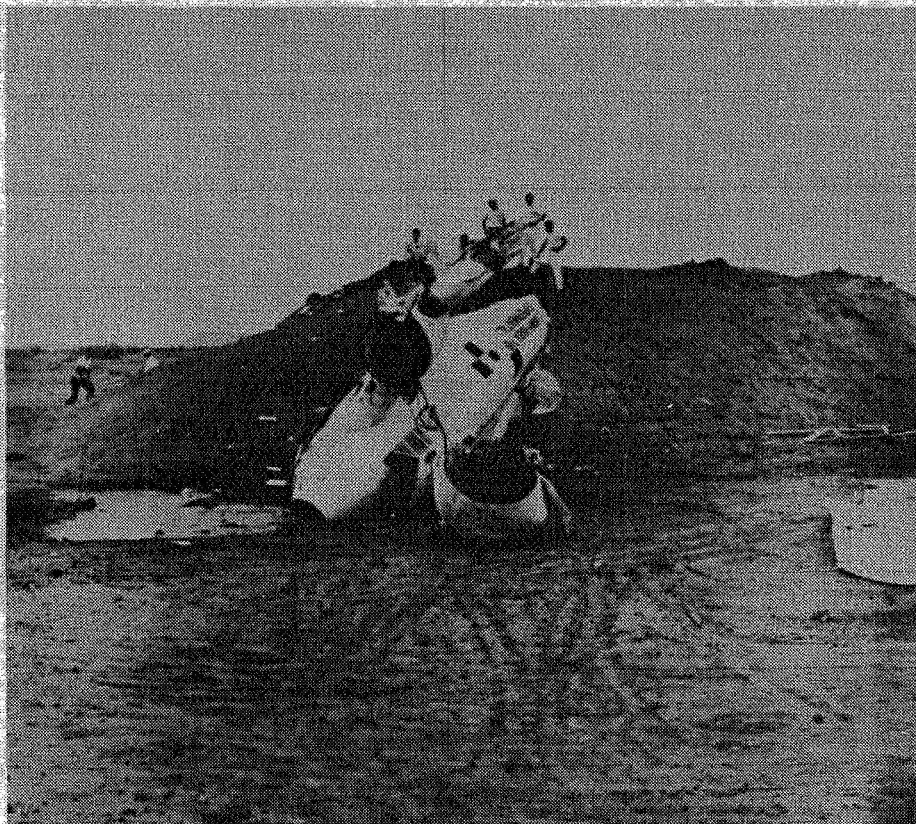
Fig. 90. C-45 Crash Test of April 1965, Looking Forward at Rearward-Facing Airseat Installation

The velocity of the aircraft at impact with the 30° sloping hill was approximately 90 mph with the aircraft turning over and coming to rest on its left side on the far side of the hill (Fig. 91).

The airseat was intact (inflated) and the dummy still in the seat after the crash (Fig. 92). The interior motion pictures were not obtained, and the accelerations of the dummy are not useful because of an apparent malfunction in the data acquisition system on board.



View Looking from the Hill Along the Flight Path



View Looking Back Up the Hill Along the Flight Path

Fig. 91. C-45 Crash Test of April 1965, Final Position of Aircraft After Crash Test

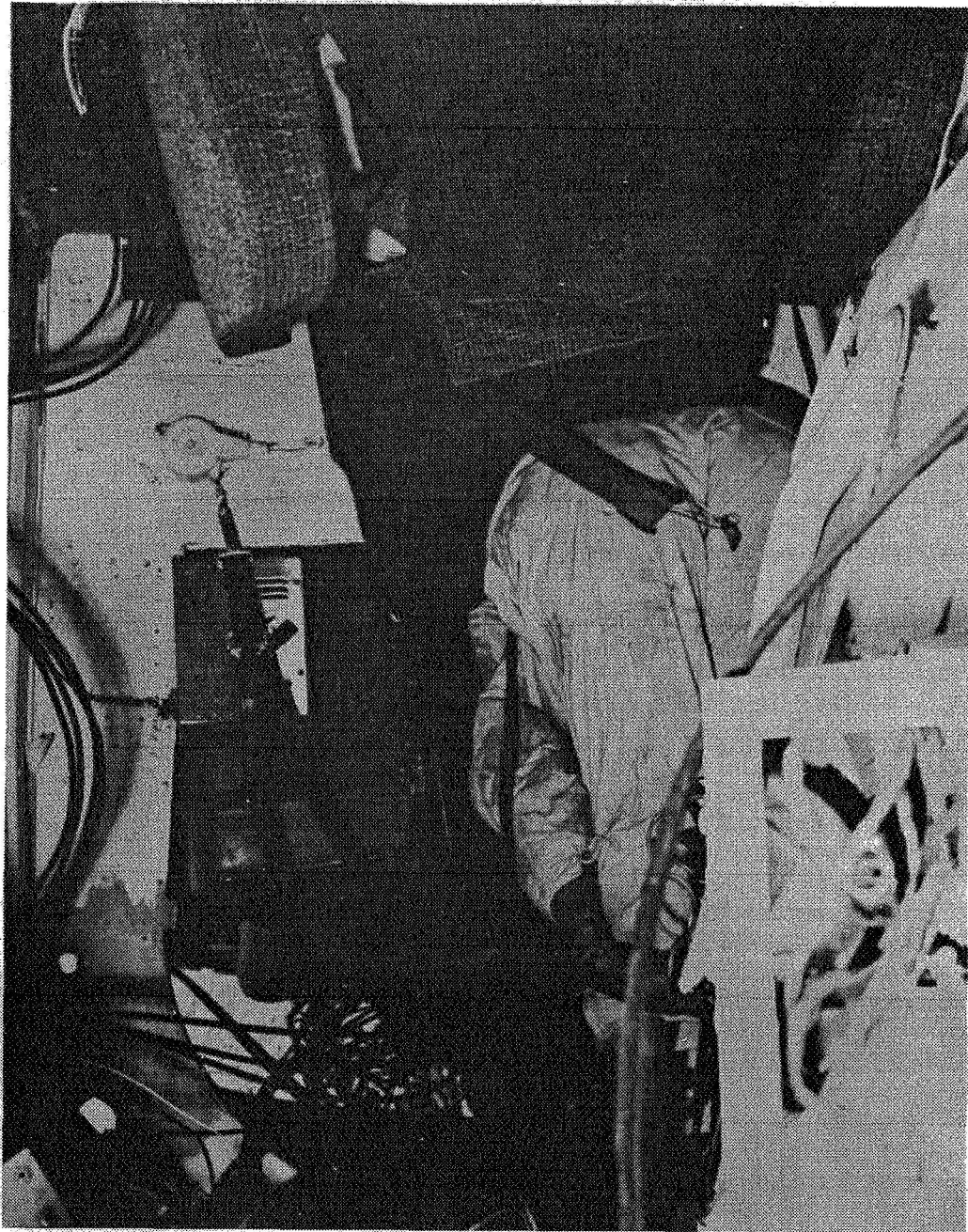


Fig. 92. C-45 Crash Test of April 1965, Airseat Dummy and Inflated Airseat After the Crash (aircraft has rolled onto its left side)

G. THE TURBULENCE ISOLATION SIMULATION TESTS

The primary need in flying in severe turbulence is to reduce the body accelerations so that unintentional and uncoordinated motions with respect to the aircraft cockpit do not occur. One could make an improved rigid restraint so that the pilot would experience just the accelerations of the aircraft and have no motion with respect to the cockpit. This could be done in conjunction with a redesign of the controls, so that all of them are right at the fingertips. An alternate approach is to isolate the crew, particularly from the higher frequency (greater than 5 cps) components of the aircraft acceleration, by means of an airseat. Figure 93 shows the comparison between the airseat and a "hard seat" at 5 cps \pm 1.5 G sine vibration input. Acceleration data from this test shows the airseat to transmit only 30% of the input acceleration to the subject's head.

A single airseat was delivered to NASA Ames Research Center for evaluation of its effectiveness for vibration isolation at frequencies associated with jet transport predominant fuselage bending, i. e., about 3 to 5 cps. ⁹⁷

The airseat was installed on the Height Control Apparatus (Figs. 94 and 95). Seat pressure was 0.30 psi and the subject's weight was 160 lb. The seat was excited by a sinewave input varying from 1 to 6 cps superimposed on a 0.25 cps sinewave of 0.1 G. Figures 96 and 97 show the results of this experiment. These results show isolation at 5 cps but not of the magnitude of the experiments conducted at Martin (Fig. 93). Several differences between the experiments are apparent from the photographs. The feet of the subject for the Ames experiment are securely fastened to the moving platform; at Martin we found this to transmit significant load to the subject. Also, the harness on the Ames experiment was apparently fastened to the moving platform. This effect can be noted by comparing the isolation characteristics with and without the harness (Figs. 96 and 97). It is our hypothesis that if we can keep the resonance overshoot (near 3 cps with the present design--Fig. 97) so that the canopy is not hit, and particularly if we can lower the resonance frequency below 1 cps by connecting the seat to a restricted volume, this turbulence isolation approach will allow operation of the aircraft at perhaps twice the RMS G which the pilot would have accepted in an ordinary restraint. Fingertip controls and perhaps key displays would be placed to move with the man. With such an airseat and controls, the aircraft could be operated at military power in spite of turbulence at the 0.4 G RMS level for example, whereas the standard aircraft is slowed down to half the speed until the RMS G gust loading is below perhaps 0.2 G. In the airseat, motion with respect to the cockpit is of such a low frequency that vision is little or only moderately impeded.

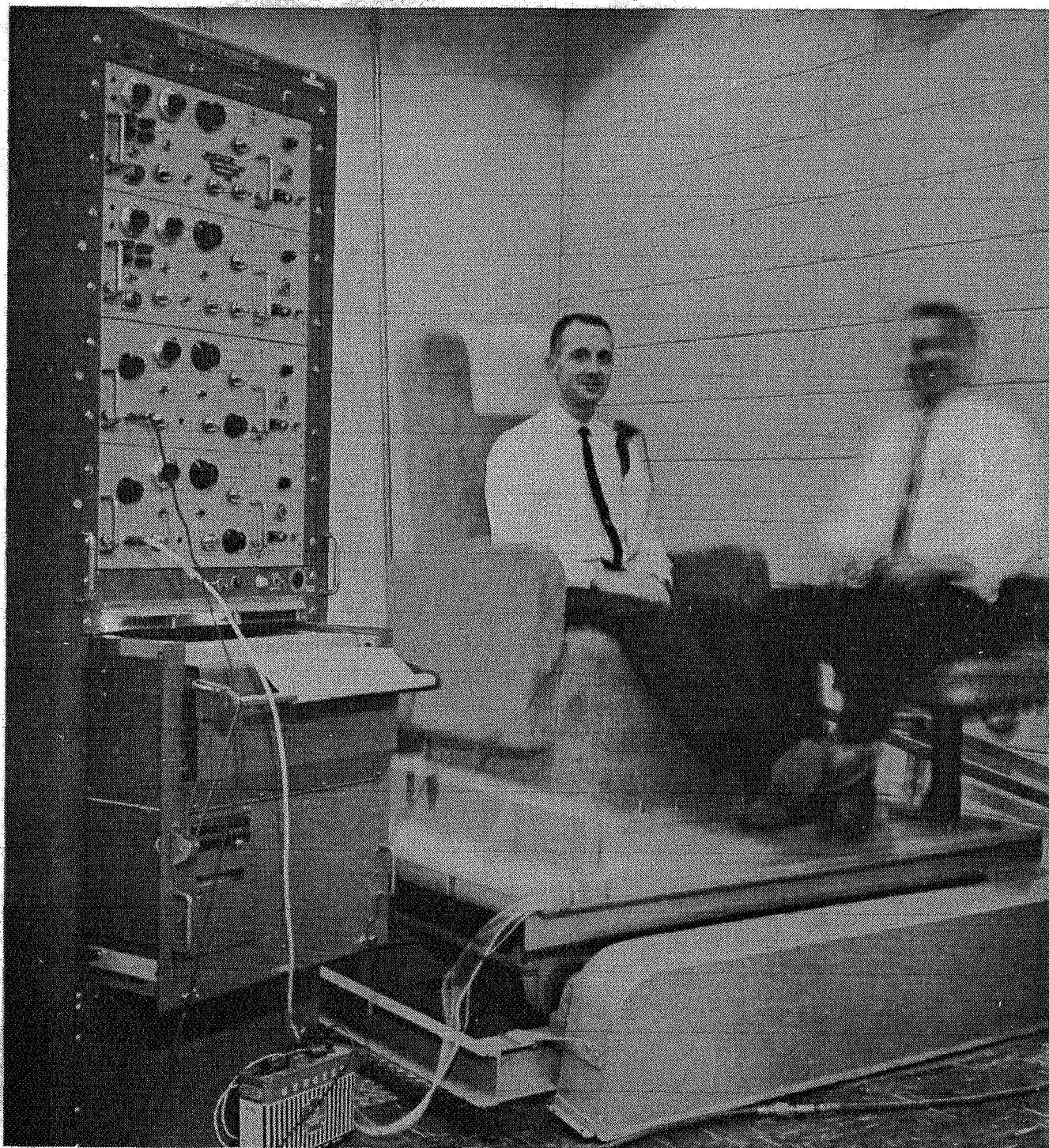


Fig. 93. Vibration Isolation Demonstration of the Airseat

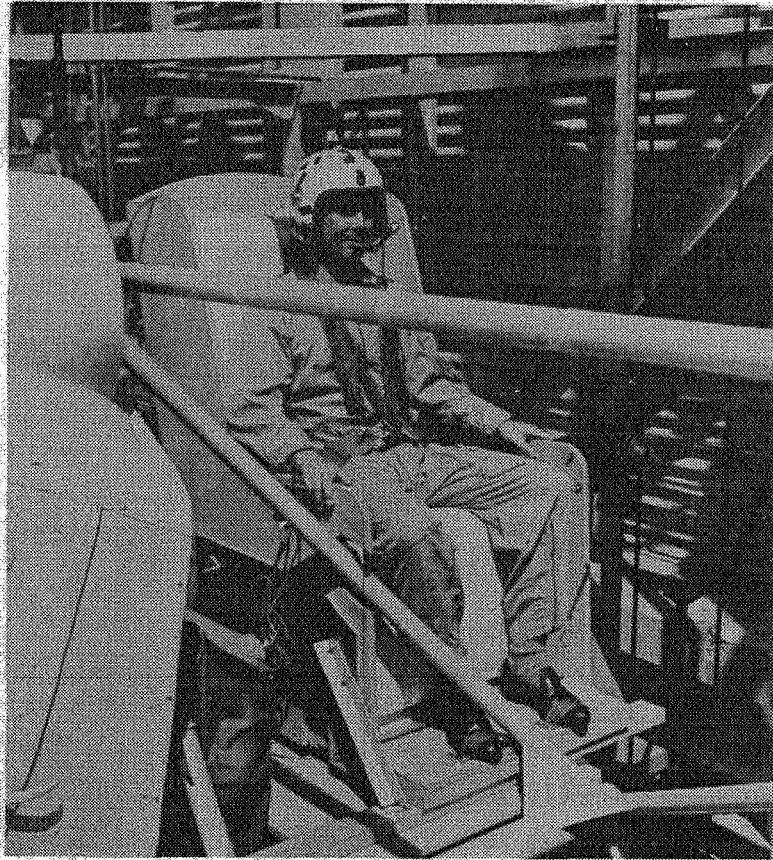


Fig. 94. Airseat Mounted on NASA Ames Height Control Apparatus for Vibration Isolation Tests (note method of foot tiedown)

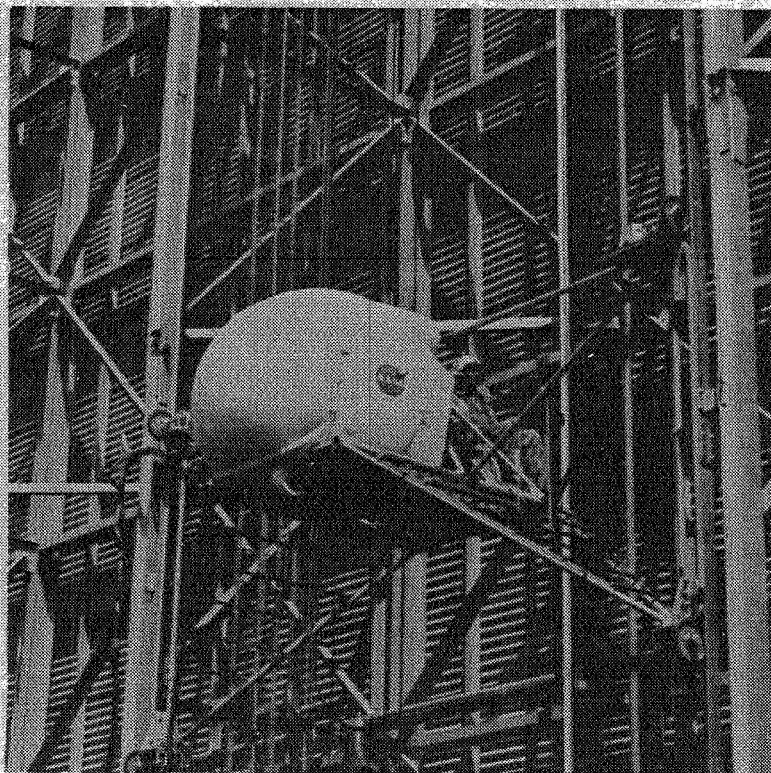


Fig. 95. NASA Ames Height Control Apparatus Overall View with Airseat Positioned

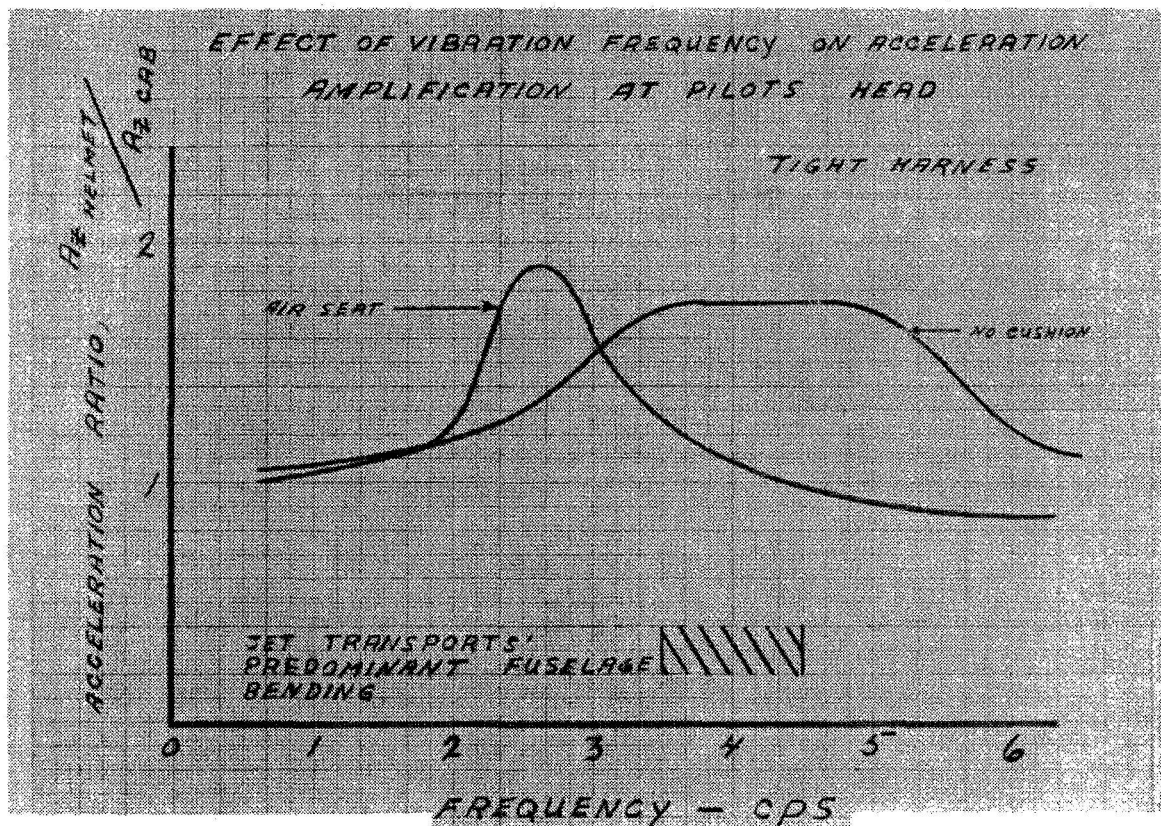


Fig. 96. Effect of Vibration Frequency on Acceleration Amplification at Pilot's Head. Airseat Test with Tight Harness

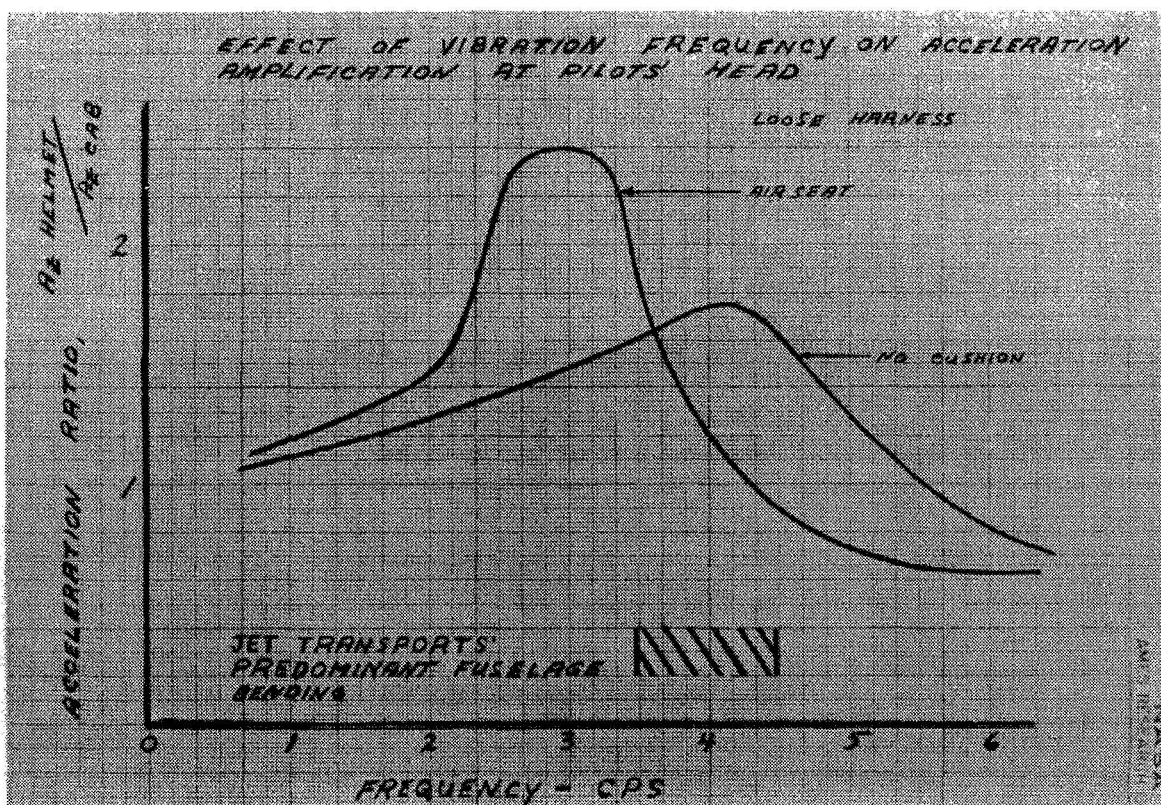


Fig. 97. Effect of Vibration Frequency on Acceleration Amplification at Pilot's Head. Airseat Test with Loose Harness

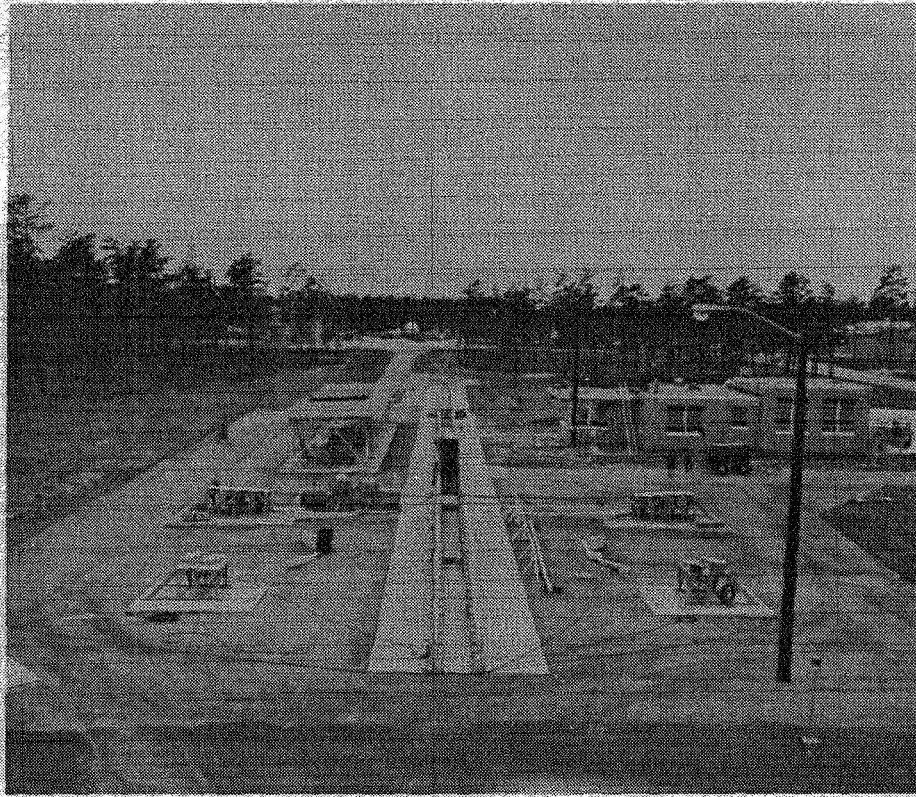


Fig. 98. FAA Catapult Facility

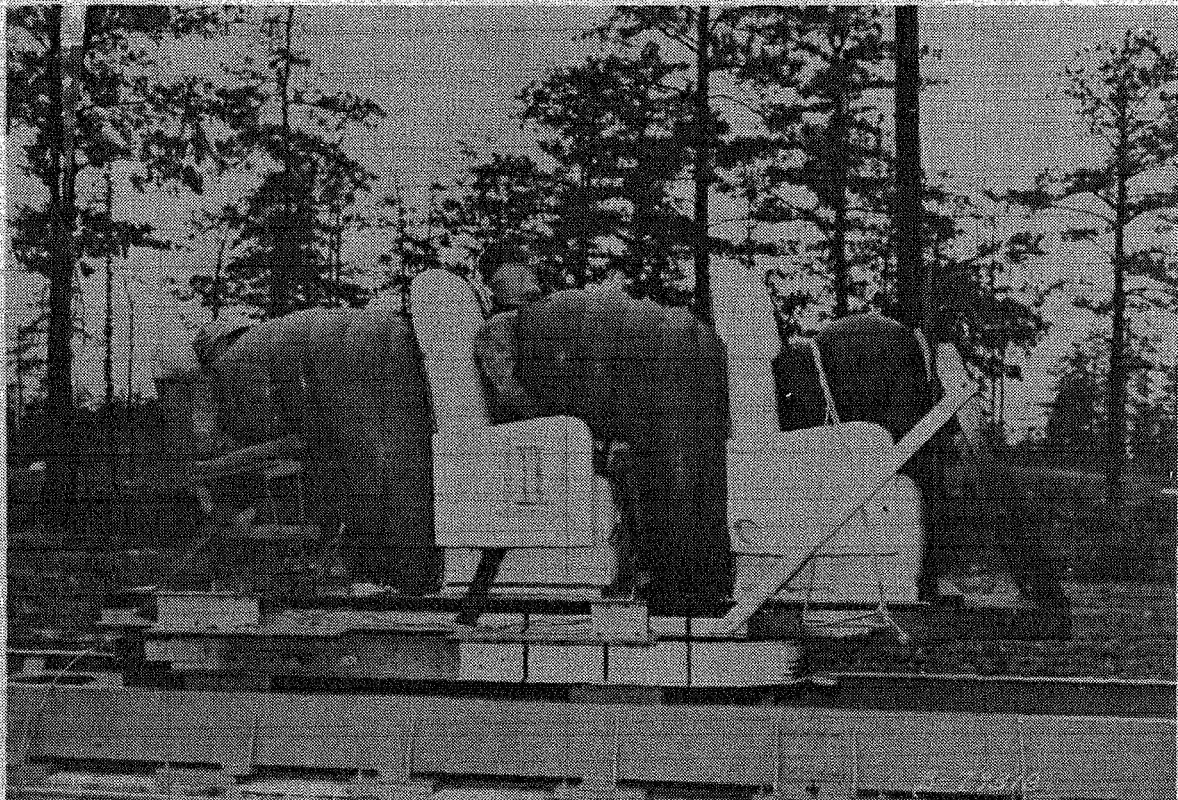


Fig. 99. FAA Catapult Track Tests of November 1965, Airstop Installation

H. FAA CATAPULT TRACK TESTS OF NOVEMBER 1965

Because of the limited data obtained in the previous experiments, a fourth addendum to the contract in August 1965 added the fabrication and testing of a single passenger airstop restraint system to be tested in a cooperative NASA-FAA arrangement on the FAA Catapult Track Facility at the National Aviation Facilities Experimental Center, Atlantic City, N. J. (Fig. 98). This arrangement permitted repeated testing at increasing impact velocities. Ten or twelve crashes were initially planned, with speeds up to 60 mph. It is noted that this program was the first technical experiment on the facility.

The test rig (Fig. 99) consisted of a wooden platform of 2 x 4-in. supports and 0.75-in. thick plywood floor. Mounted to the platform was: (1) an unoccupied airseat forward with an airbag and simulated bulkhead to react the aft airbag loads; (2) an airseat with a 50th percentile anthropomorphic dummy (instrumented for G_x , G_y , G_z accelerations in the upper chest cavity) protected by a chest airbag which had an extension to provide support for the lower legs; and (3) a regular airline seat (with additional tie-down to reduce failure) with a 50th percentile anthropomorphic dummy (instrumented for G_x and G_z accelerations in the upper chest cavity) protected by a chest airbag, also giving lower leg support (Fig. 99). To achieve maximum effect of the airseat in the longitudinal impact condition, a 4-in. wide lap belt was added, securely fastened to the skid. This allows a rotation down into the airseat during the longitudinal impact case with upper body rotation into the chest airbag. The same type lap belt was added to the dummy in the standard airline seat.

Ten tests were conducted in the forward facing configuration (longitudinal impact) at impact velocities from 29 to 87 mph and utilizing the maximum braking capabilities of the facilities. Peak accelerations for this series of tests are listed in Table 10 and are shown graphically in Fig. 76. This curve shows the additional 3 G isolation provided by the airseat. In all cases, the dummy in the airstop restraint remained in the airseat and would probably have "survived" the crashes. Adding the 18% sled rebound velocity, the velocity changes of these tests were from 34 to 103 mph.

Figures 100a and 100b show the before and after conditions for Test Run No. 6. Prior to Run No. 6, two runs at speeds near 50 mph resulted in damage to the nylon reinforcing straps in the airseat dummy chest airbag, as can be seen in Fig. 100a. This condition resulted in the failure in the chest airbag during Run No. 6. Even with the airbag failure, the dummy was protected during the impact, receiving only $-6.2 G_z$ and $-2.7 G_x$ maximum accelerations. Figure 100 shows Test Run No. 7 impacting at 57.3 mph at near maximum dummy displacement.

Figure 101 shows the condition after the impact.

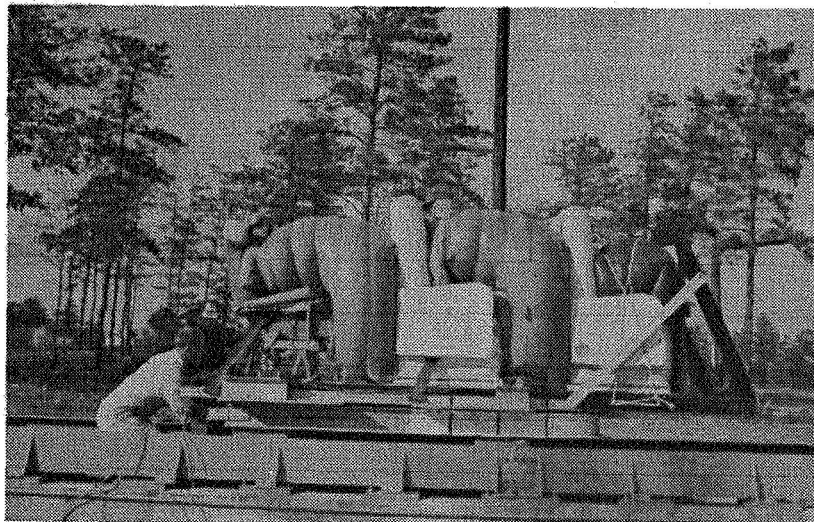


Fig. 100a. FAA Catapult Track Tests of November 1965. Airstop System Prior to Test Run No. 6. Note Reinforcing Straps in Airseat Dummy Chest Airbag. Result of Previous Impact at 50 mph

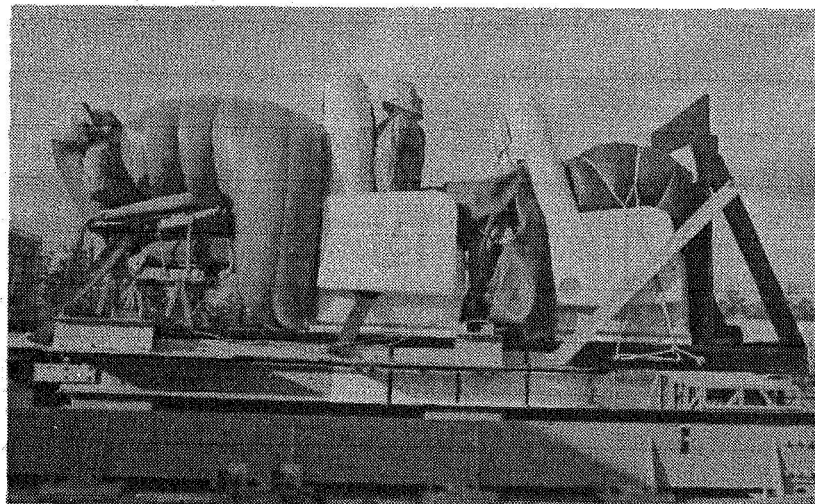


Fig. 100b. FAA Catapult Track Tests of November 1965. Airstop System After Test Run No. 6. Airseat Dummy Chest Airbag Has Broken at the Point Where Reinforcing Straps Were Damaged

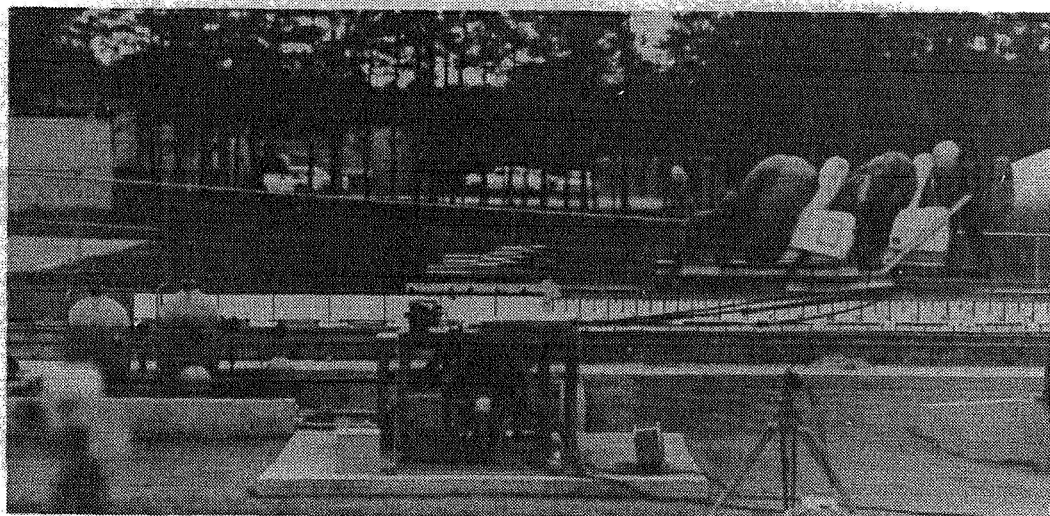


Fig. 100c. FAA Catapult Track Tests of November 1965. Near Maximum Displacement Shown During Test No. 7 at 57.3 mph Into the Restraining Wire (68 mph velocity change, with sled rebound)

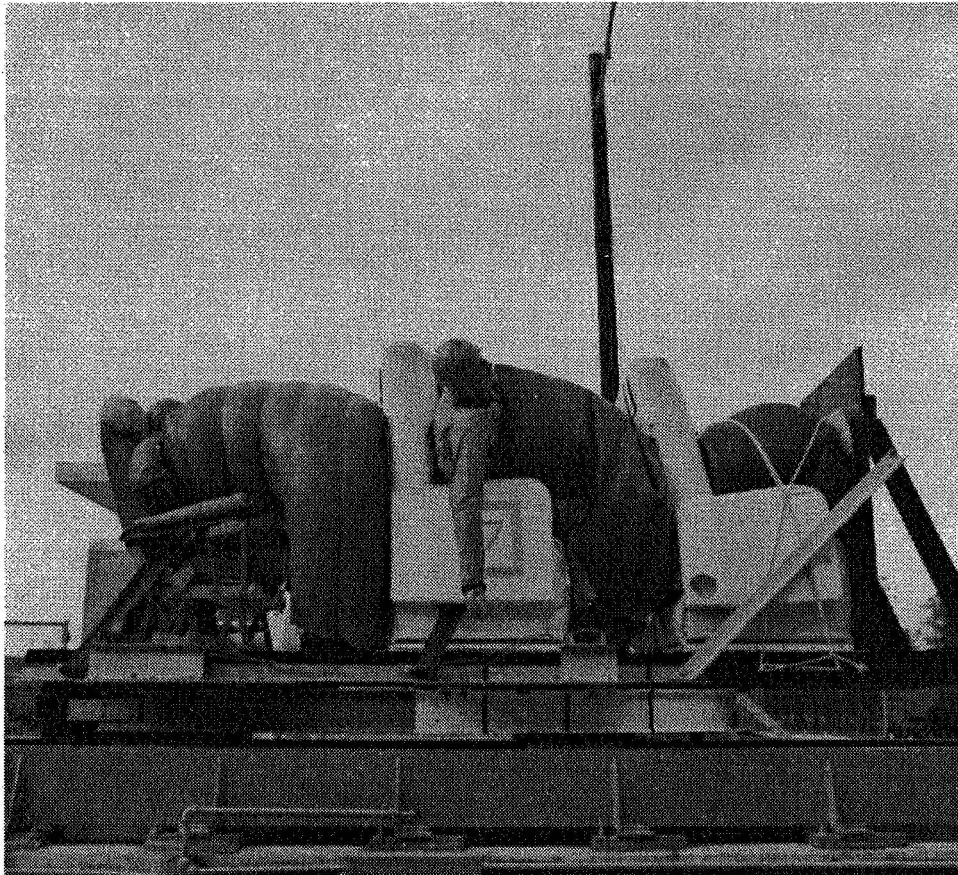


Fig. 101. FAA Catapult Track Tests of November 1965. Dummy Position After Test Run No. 7 at 57.3 mph

In Test Run No. 9, at 71.2 mph, the standard seat in back of the airseat yielded forward, coming unriveted and punching down through the 0.75-in. plywood floorboard. The lap belt of this dummy failed, the chest airbag failed (Fig. 102), and the dummy was thrown out on the ground (Fig. 103).

The airseat dummy received an "uninjured" loading. Figure 104 presents the time history accelerations for this test run with the airseat dummy receiving loadings of $-10.6 G_x$ and $-20.7 G_z$ for a sled deceleration of $-21.2 G_x$ (the remaining time-histories are presented in Appendix C). Two oscillographs were used in recording the acceleration data. The oscillograph speed range settings did not allow both recorders to operate at the same speed; hence, any correlations between the longitudinal and the vertical and lateral accelerations would have to be made on a single point basis using the time references as noted. The peak accelerations do occur at about the same time as would be expected with this type of restraint and no further time correlation was deemed necessary. In the final test, Run No. 10 at 86.5 mph with no dummy in the broken back seat, two steel bolts failed just after maximum displacement into

TABLE 10

**Airstop Restraint System
FAA Catapult Track Tests**

Peak Accelerations

Run No.	Velocity (a)		Sled Acceleration			Airstop Dummy Accelerations			Standard Seat Dummy Accelerations		Run-out Distance (ft)	Airstop Dummy		Regular Seat Dummy	
	(ft./sec)	(mph)	\bar{g}_x	\bar{g}_y	\bar{g}_z	G_x	G_y	G_z	G_x	G_z		Resultant Acceleration (G)	Forward Tilt Angle (deg)	Resultant Acceleration (G)	Forward Tilt Angle (deg)
1	45.74	31.2	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	10				
2	55.14	37.6	(b)	+2.5*	+4.9	(b)	-3.4	-7.5	(b)	-9.1	10				
3	71.00	48.4	(b)	+1.2	+4.6	(b)	-8.7	-15.5	(b)	-14.3	13				
4	72.4	49.4	-12.1	(b)	+5.4	(b)	-6.0	-20.4	(b)	-14.0	12				
5	45.56	31.1	-6.4	+0.6	+5.5	-3.4	-1.8	-6.2	-7.7	-7.5	10	7.1	61 (e)	10.8	44
6	47.12	32.1	-7.1	+1.4	+2.6	-2.7	-2.7	-6.2	-7.2	-7.7	10	6.8	66	10.5	47
7	83.99	57.3	-16.7	+4.2	+10.2	-8.0	(b)	-15.0	-11.4	-19.6	14	17.0	62	22.7	60
8	43.03	29.3	-5.9	negl	+3.8	-4.8	(b)	-2.6 [?]	-7.1	-6.4	9				
9	104.42	71.2	-21.2	+5.5	+17.9	-10.6	+3.0	-20.7	-14.1 (e)	-20.9 (e)	16	23.3	63	25.2	56
10	126.88	86.5	-24.4	+7.6	+31.3	-10.7	+8.3	-27.2	(b)	(b)	17	29.2	68		

* + designation reflects a vibration of the sled during the arresting phase. Predominant frequency was 60 to 70 cps.

NOTES:

- (a) A preliminary evaluation of the motion pictures of Run No. 9 indicates a rebound velocity of 18% of the impact velocity. Hence, the velocity change of these impact events is some 18% greater than shown here.
- (b) No data--questionable calibration, or channel response oscillograph malfunction, calibration not available. In run 10, the standard seat dummy was removed.
- (c) Dummy came free during this test, breaking the seat belt, thus reducing the peak acceleration.
- (d) These peak loads occurred as a transient condition after the sled had decelerated and are probably a result of the failure of the skid.
- (e) The forward tilt angles are calculated from the accelerometer readings. See text for discussion.

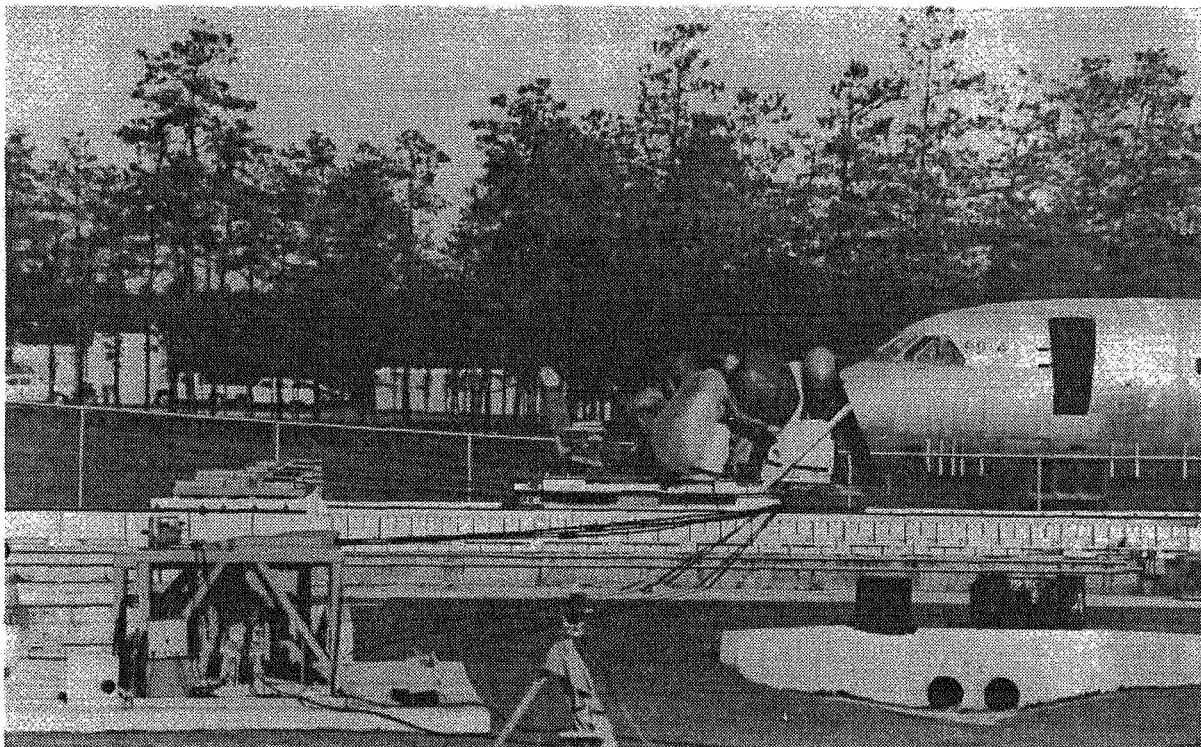


Fig. 102. FAA Catapult Track Tests of November 1965. Near Maximum Displacement Shown During Test Run No. 9 at 71.2 mph. Aft Dummy Has Broken its Lap Belt and the Airbag Is About to Fail Under the Additional Load. Seat Failure Preceded Lap Belt Failure (84 mph velocity change with sled rebound)

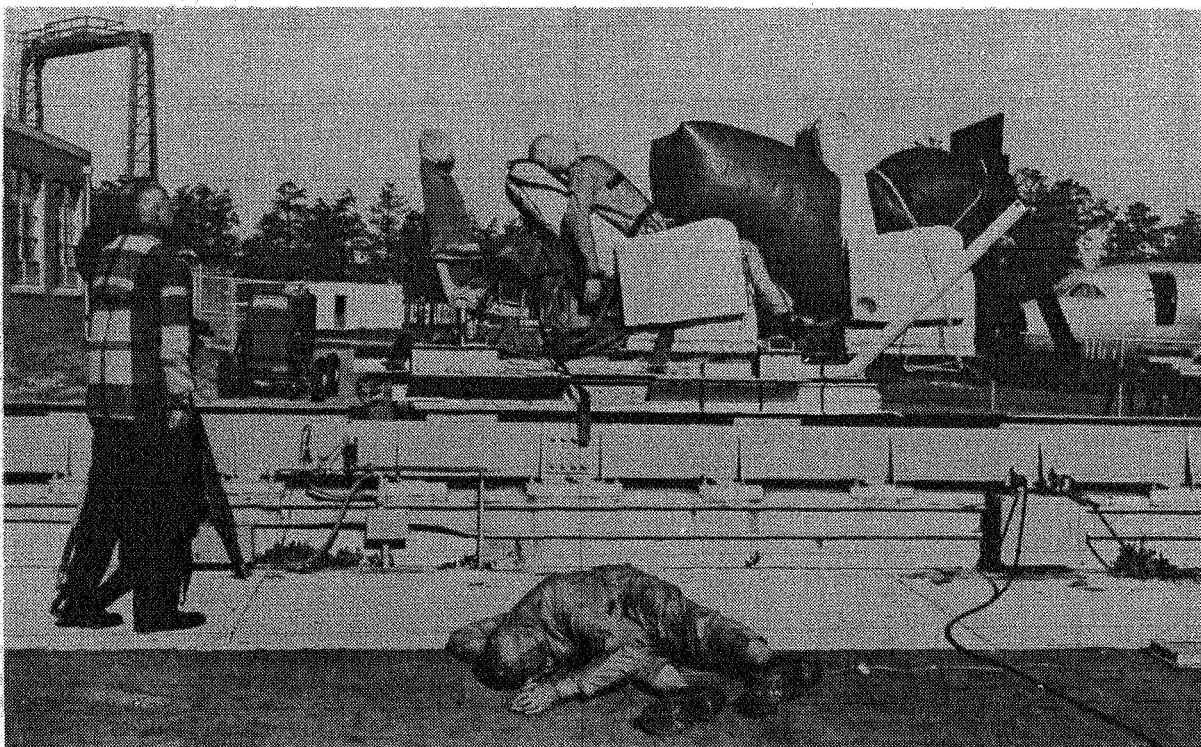


Fig. 103. FAA Catapult Track Tests of November 1965. Airstop System After Test Run No. 9. Aft Dummy Was Ejected from its Seat During the Catapult Car Rebound After the Seat and Lap Belt Had Failed. Airstop Dummy was Uninjured (84 mph velocity change with sled rebound)

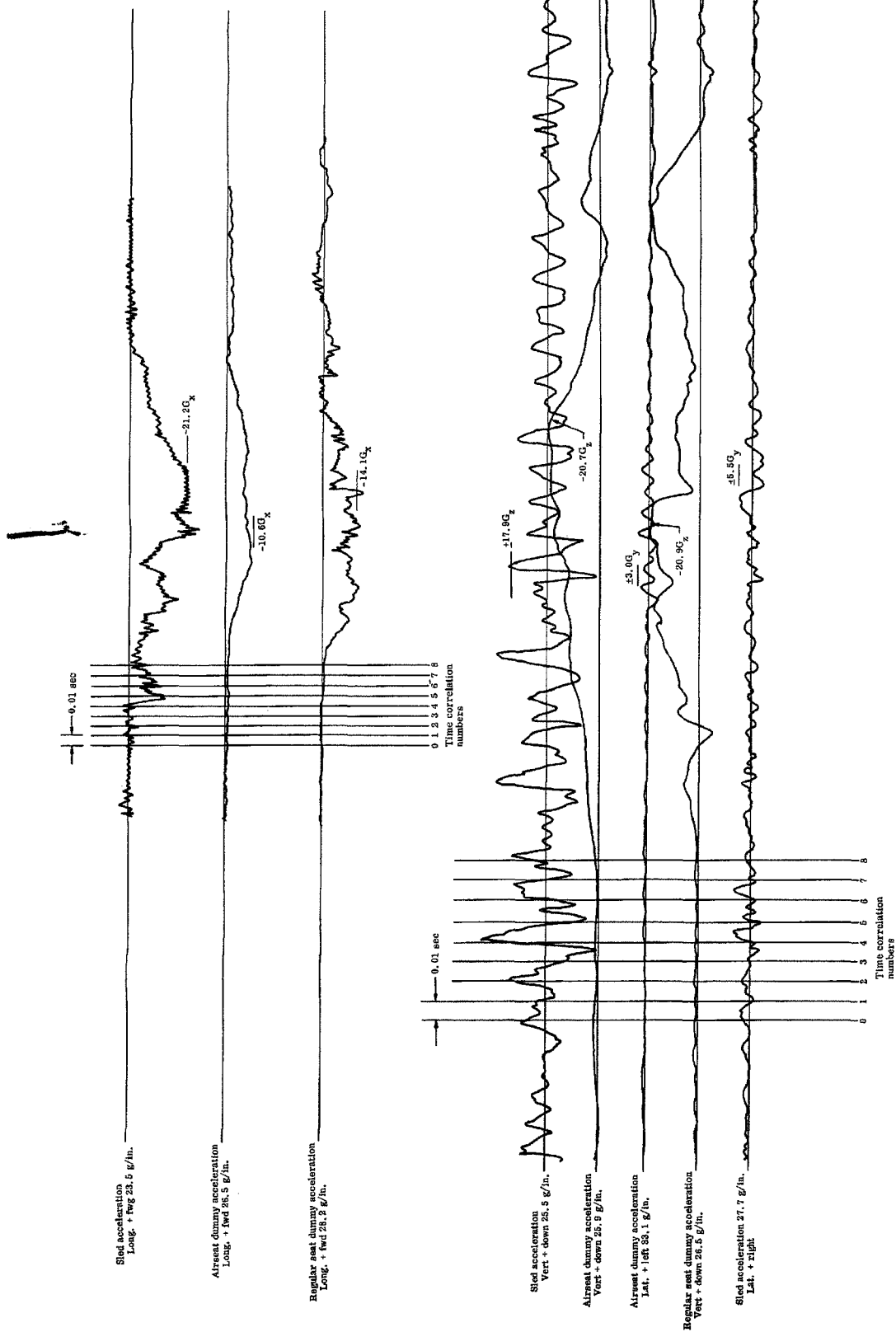


Fig. 104. Airstop Restraint System FAA Catapult Test No. 9--Velocity: 104.42 fps

the airbag system (Fig. 105) allowing the skid structure to break in half just in front of the airseat. Because the break came at maximum displacement, hence no residual forward velocity, the still inflated chest airbag with the front of the structure fell to the catapult track at this point (Fig. 106).

The dummy was still attached to the still inflated airseat by the lap belt (Fig. 107) but with the loss of upper body support had tipped off to the left side and would have been injured in partly dragging across the arresting wires during the catapult car rebound. During the stopping or crash phase, the smooth dummy chest load peaked at $-27.2 G_z$ and $-10.7 G_x$ with about $-24.4 G_x$ deceleration of the sled, which appears to be quite survivable.

In examining the data from this series of tests, it is noted that the G_z accelerations are much higher than the G_x accelerations as these values are reported to us by the FAA experimenters. If we calculate the resultant acceleration and the angle of the resultant, we find that the airseat dummy would have to rotate through about a 60° angle to account for this combination of dummy accelerations to give a horizontal resultant. Surprisingly, this rotation angle does not change very much (61 to 68°) for extensive impact speed changes (29 to 87 mph). The still photographs and motion pictures do not show this extreme forward rotation. However, since the dummies used were fully articulated, it is possible that the upper chest where the accelerometers were mounted rotated with respect to the pelvis, accounting for the higher G_z acceleration even though the back does not appear to be rotated far enough. In any case, the accelerations measured are considered to be survivable. We accept the sled and resultant dummy accelerations, but are not yet satisfied as to the rotations computed.

We also considered the possibility that the instrumentation was mixed, and G_x values should be interchanged with G_z values. After re-examining the wiring and dummies, Don Voys of the FAA reported that the instrumentation appeared correct, and that the upper chest (and accelerometers) must have indeed rotated more than the external views indicated. Clearly, an experiment of this type would be better done with additional instrumentation and direct calibration, including hip and head accelerometers. It is hoped that this excellent FAA facility can be further equipped. Figure 108 summarizes these crash results.

I. THE COMPLETE AIRSTOP SYSTEM

Although safety experts are beginning to recognize the impact isolation characteristics of airbag restraints, some have expressed concern that the bags would impede egress from the cabin after the crash. In our initial design we suggested that a pressure or preferably an accelerometer transducer would sense the crash, then, after a time delay of perhaps 10 sec in case there were multiple impacts in the crash, would automatically actuate a valve (or

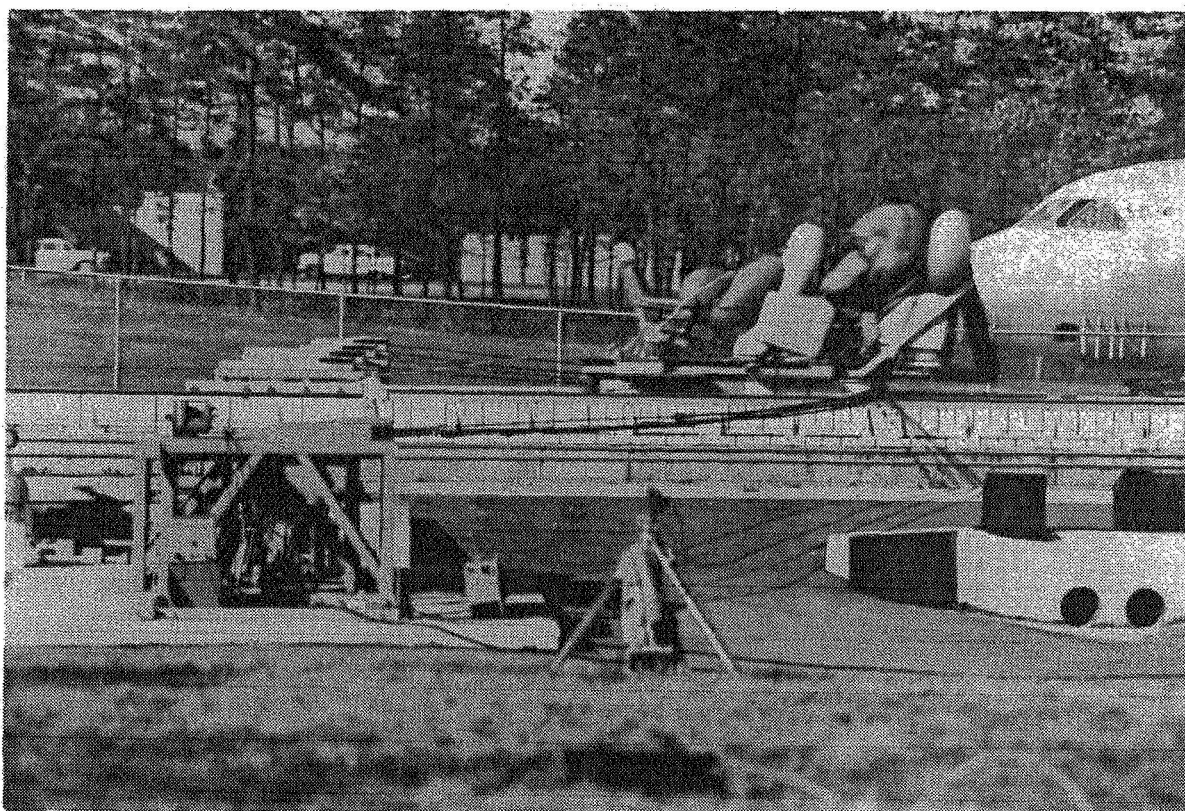


Fig. 105. FAA Catapult Track Tests of November 1965. Near Maximum Displacement Shown During Test No. 10 at 86.5 mph. Aft Dummy Has Been Removed (103 mph velocity change with sled rebo

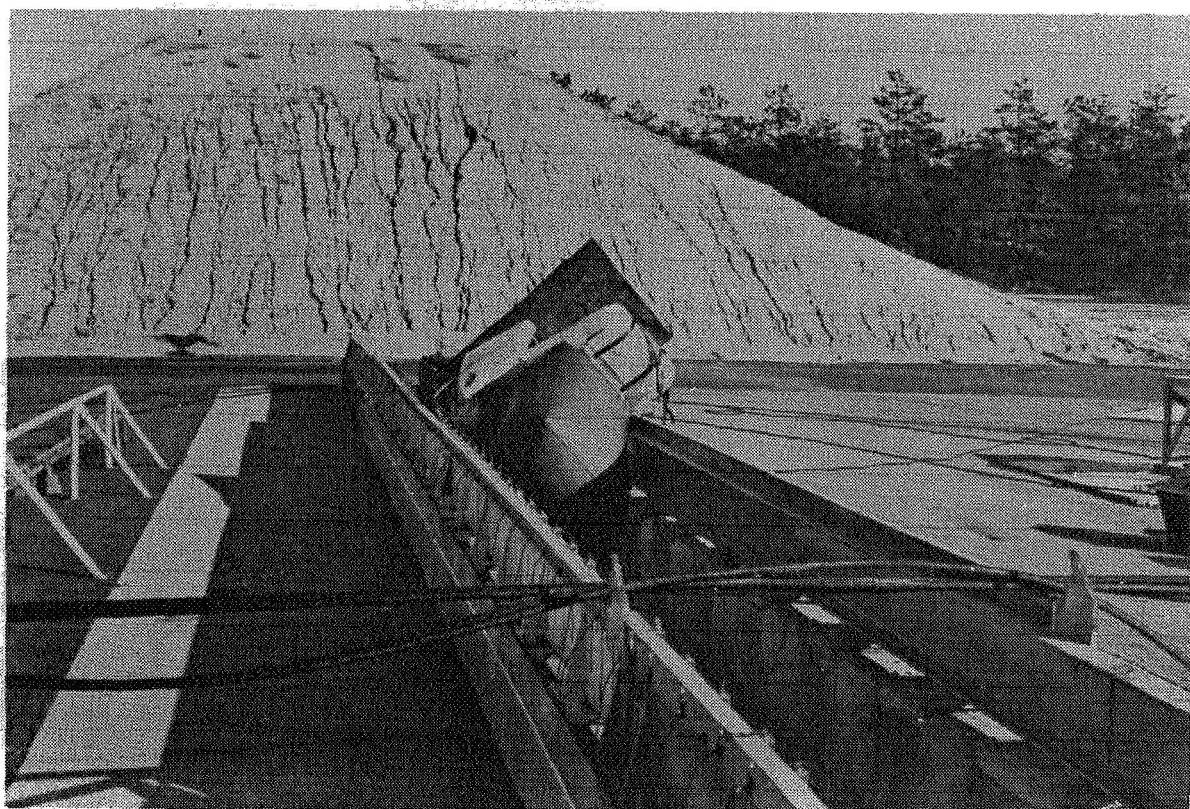


Fig. 106. FAA Catapult Track Tests of November 1965. Forward Portion of the Skid Where it Fell Aft Bolts in the Skid Failed During Test Run No. 10

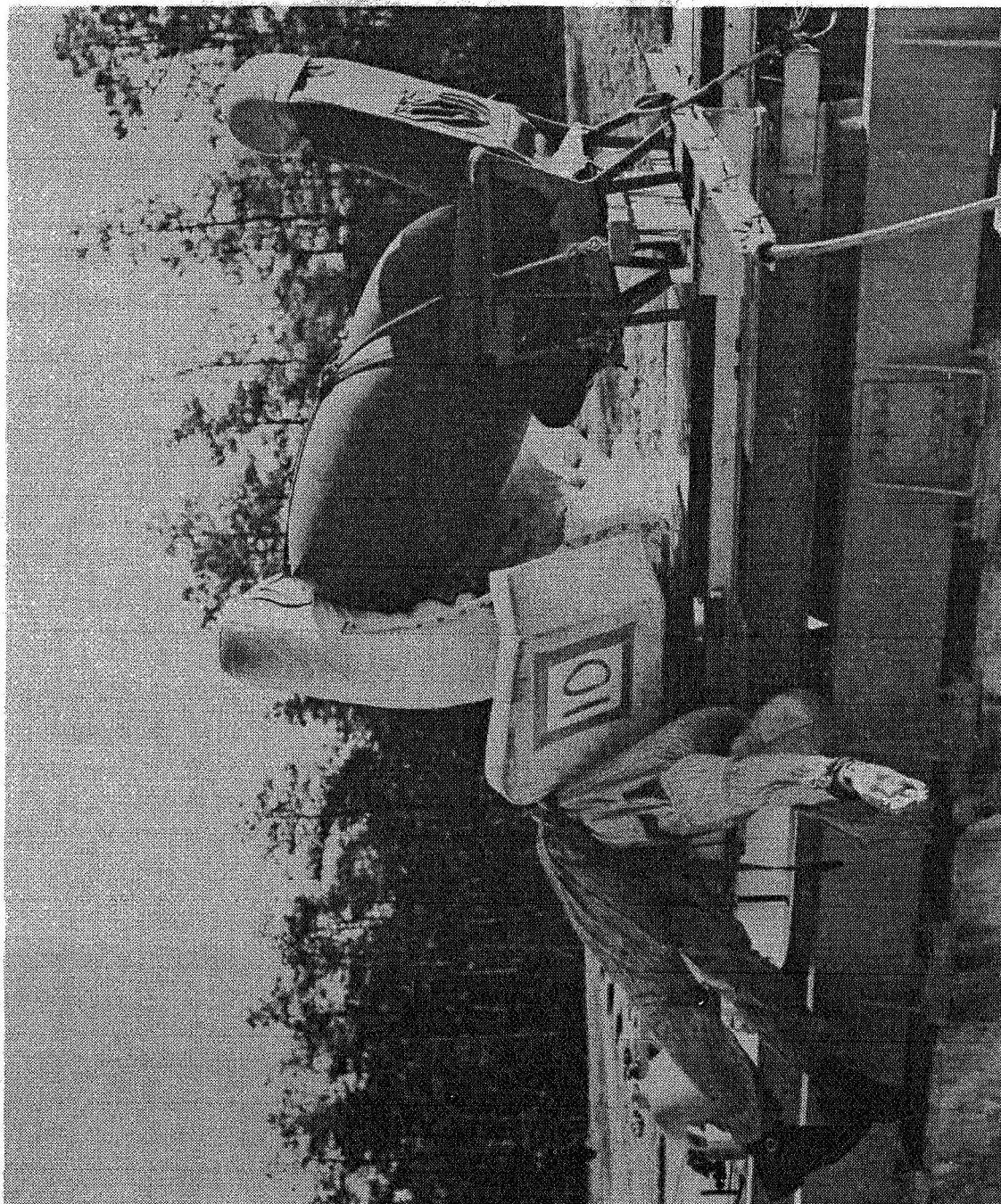


Fig. 107. FAA Catapult Track Tests of November 1965. The Airstop Dummy After the Sled Failed, Removing the Chest Airbag. The Lap Belt Holding the Dummy to the Airseat Held. The Limbs Hit the Arresting Wires, but the Dummy Apparently Received a Survivable Load, Although with Injury.

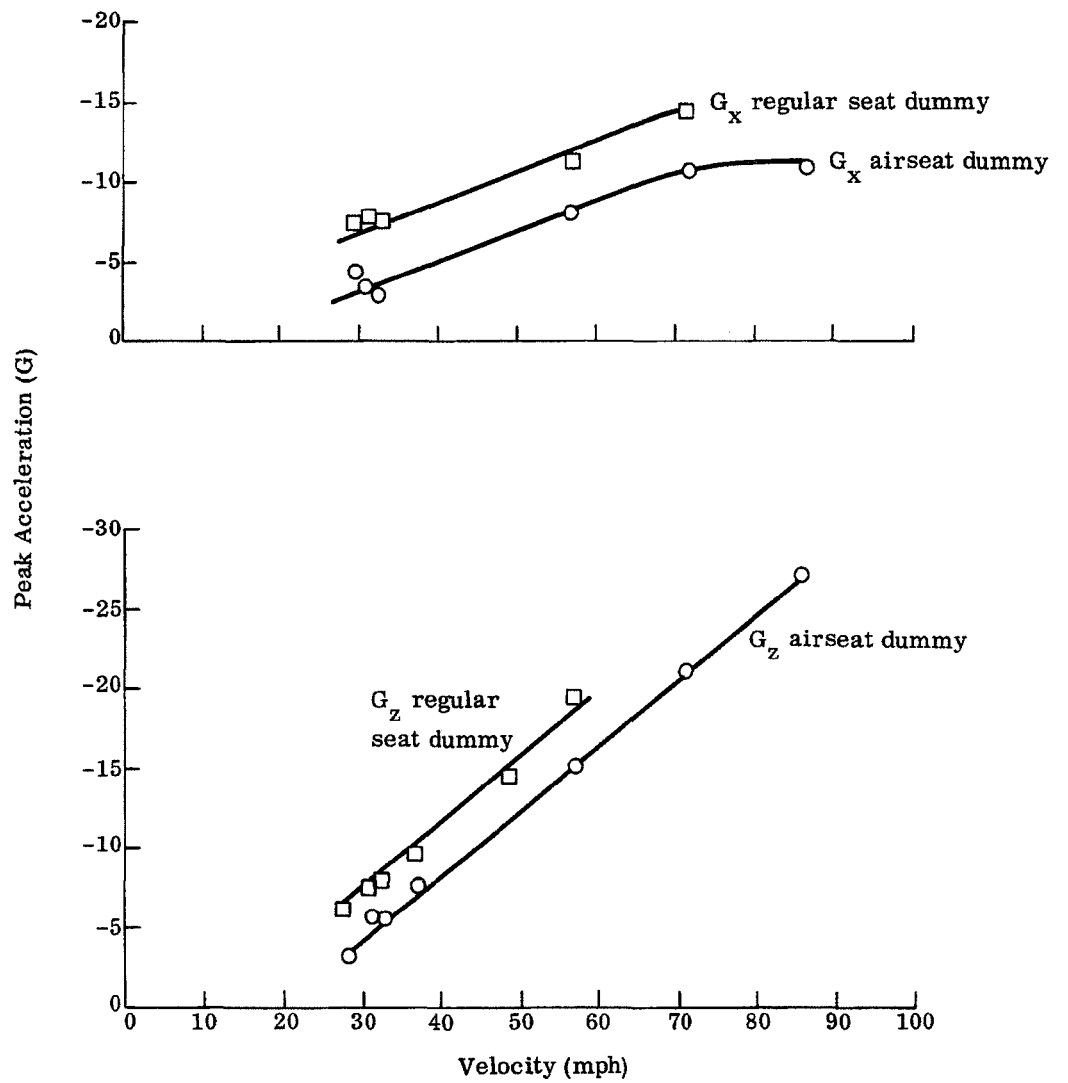


Fig. 108. FAA Catapult Track Tests of November 1965. Airstop Restraint System Peak Accelerations Versus Sled Impact Velocity

valves at each seat) to deflate the bags. Even when deflated, the latex chest bag may hang onto the lap. Hence, we have sought means to positively remove the bag on deflation. The plastic bags are far less an impediment. We have experimented with flat coil springs (Fig. 109) and elastic bands or bungee chords (Fig. 110) in the bag material to cause this automatic roll-up, aided in some cases, including Figs. 109 and 110, by applying a vacuum to the inside of the bag. We are satisfied that engineering refinements can provide chest and foot bags which will essentially disappear into the seats, automatically after a crash, or when not in use. We now see the possibility that these bags, of transparent material, would be inflated by the stewardess, suggesting that people sit back, then actuating a switch prior to every takeoff and landing as part of the normal procedure, rather than to attempt to inflate them just before an emergency. After the normal takeoff or landing, the stewardess would actuate the automatic rollup of the bags.

An earlier criticism of the airbag restraint was that it would add weight, reduce payload of the commercial airlines, and so not be readily accepted by them. We weighed a commercial aircraft, two-passenger seat at 59 lb; our dual airseat, still crudely engineered, weighs 35 lb. The four chest and foot bags would add 8 lb. The inflation-deflation mechanism, perhaps an impeller fan at each seat, or a valved connection to the booster ventilation air supply (since 3 in. of water pressure may be adequate for the chest and foot bags) with valves and automatic deflation circuitry, could then weigh 15 lb at each double seat and our system would still weigh less than present seats. We would remove metal trays from the seat backs, perhaps using inflated trays.

The Martin Company fabricated an Airbag Restraint Display (Fig. 111) for demonstration purposes at the June 1964 Meeting of the American Institute of Aeronautics and Astronautics in Washington, D. C. The exhibit was very popular. This interest in the display led to its being utilized in the Martin Exhibit at the Air Force Association Meeting in September 1964, at the Hotel Sheraton, Washington, D. C., where it was selected by the Air Force to receive tour presentation emphasis, with over 2000 people hearing these lectures and some 2000 others seeing the display without the lecture. Approximately 200 people sat in the seat and experienced the chest airbag inflation-deflation cycle. The display was again utilized at the Paris Air Show in June 1965 where more than 50,000 persons viewed the system and its operation.

Based on these presentations to the public and their comments as they experienced the functioning of the restraint, the system appears to be acceptable to the general public. Women and children found the restraint experience entirely acceptable. Even if the restraint covers the child's head, the low pressure allows the head to be moved. Breathing is not a problem even if the full face is covered because of the interstices present in the inflated airbag; the plastic is not of the cloying smothering type.

The fully developed "airstop" restraint, for land, air, space or water vehicles, activated before impact, would provide inflated structures, with their controlled yielding on impact, in all directions around the people in the vehicle.



Fig. 109. Automatic Rollup of the Airstop Chest Airbag



Fig. 110. Airstop Chest Airbag Shown Deployed from Storage Area in Seat Back

Figure 112 is a sketch of the multiple seat "airstop" installation in a vehicle, with airseats and chest and foot airbags. Figure 113 is a sketch of a possible Airstop Control Panel, suggested for a flight vehicle, available at the pilot and stewardess positions.

The operation of the "airstop" restraint system is here described, using the numbered items on Fig. 112. The system is described for a passenger aircraft, but would be generally applicable to other transportation vehicles. The passenger of the vehicle (1) may place his hand luggage (2) under the seat and sit down. He may have a seat belt (3) to utilize, which is attached to the back of the seating surface (4) and to the floor with a flexure to allow some motion of the man and the deflecting seat forward in the event of a crash, without initially transmitting a direct load through the belt to the floor. This seat belt provides restraint during periods of moderate turbulence. In severe turbulence, the airbags would be inflated. Prior to takeoff and after advising the passengers to sit back and relax, the pilot or stewardess utilizes the Airstop Control Panel (Fig. 113) at his or her position and actuates the impeller switch (5) to the "inflate" position. This starts the impellers (6) at the base of each of the seat sections (for example, in each two or three seat unit). The pilot or stewardess then actuates the bag valve switch (7) to "open," which operates the electrically actuated valve (8) allowing air from the impeller to move up the flexible tube to inflate the chest bag (9) from its housing in the seat back (10) and the foot bag (11) from under the seat. The impeller is of a design to give a pressure of just a few inches of water pressure (five for example) above atmospheric pressure. It draws its air supply from the cabin. After the bags are filled (in perhaps 10 sec) the bag valve switch (7) is closed and the impeller switch (5) is turned off. The bags hold their pressure during the takeoff or landing. After it is completed normally, the bag valve switch (7) is again opened by the pilot or stewardess, and the impeller switch (5) is set to "deflate." The chest bag retracts into its compartment (10) as the waning pressure allows the retraction mechanism to operate (for example, wires or bungee chords in the sides of the bag spring loaded to retract the bag when it is not pressurized). The foot bag (11) retracts under the seat.

If the takeoff or landing is not completed normally and there is a crash, the inflated airbags and the airseat provide significant load isolation for the passengers. Following a moderate or severe crash (longitudinal loads above perhaps $-3G_x$), deflation of the bags and seats to facilitate passenger egress from the aircraft does not require pilot or stewardess action, but is automatic. A possible mode of accomplishing this is as follows: the crash acceleration actuates a mechanical acceleration sensing--unlatching G switch (12), which is indicated on the airstop control panel by an automatic deflation warning light (13). The acceleration switch releases a mechanical interval timer (14), which provides a time delay of perhaps 10 sec before bag deflation in case there are multiple impacts in the crash. If for any reason the pilot does not want bag deflation, for example, if he bounces on landing and remains airborne for another pass yet sees the automatic deflation warning light come on, he can operate the deflation override button (15) which actuates an additional electrical time delay



Fig. 111. Airstop Restraint System Display

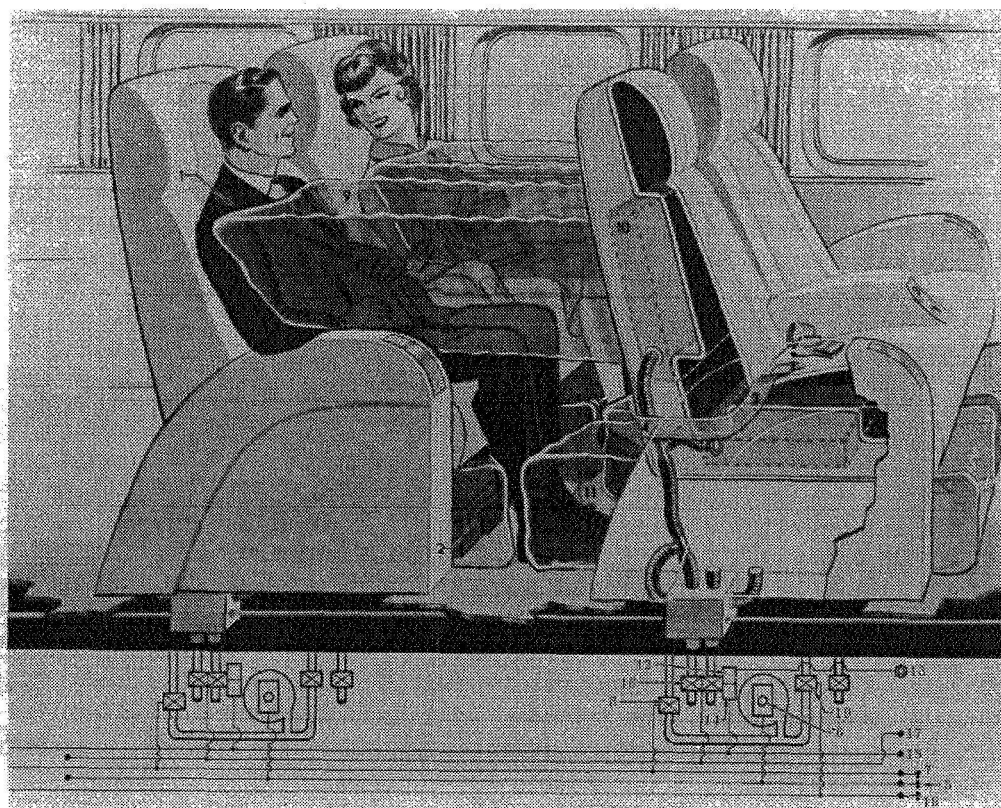


Fig. 112. System Concept of a Complete Airstop System

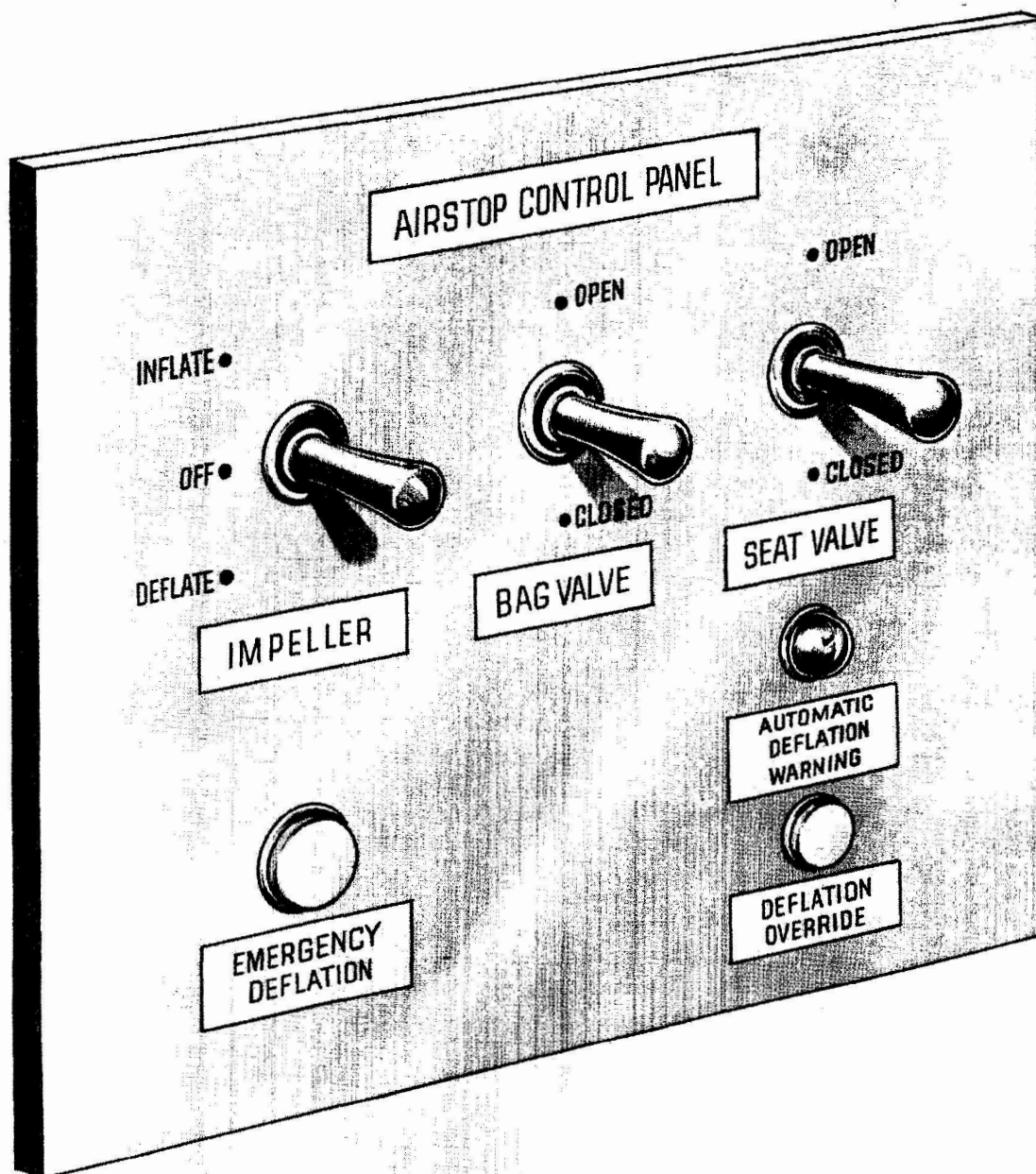


Fig. 113. Control Panel for Pilot and Stewardess Operation of a Complete Airstop System

latching solenoid in (14). At the end of the time delays, the mechanically driven dump valves (16) open, releasing the air from the chest and foot bags and from the airseats into the cabin which aids in blowing smoke from the cabin and opens up the entire cabin volume for egress passage. Note that the automatic deflation devices are at each seat unit, with a basic mechanical operation independent of loss of electrical power. Hence deflation and release from the crash would occur even if the aircraft were severely broken up.

If the crash is less severe than $-3G_x$ and the aircraft condition does not require emergency egress, after coming to a stop the pilot or stewardess can operate the emergency deflation button (17), which actuates an electrical solenoid releasing the dump valves (16), and again opening the entire cabin volume for rapid egress by collapsing the bags and seats.

If there is any circumstance whereby a flight must be continued after the seats have been deflated, as after a hard landing at an emergency field in wartime from which the pilot must take off without full maintenance, or some misuse or malfunction of the equipment in flight, the mechanical dump valves and their time delay and acceleration trigger latches can be rewound or reset at each seat, then the pilot or stewardess can operate the seat valve switch (18) to "open" and the impeller switch (5) to "inflate," and reinflate the seats (preferably with the passengers standing) through the valves (19) to the impeller pressure, which is sufficient for emergency operation. The seat valve switch (18) is then actuated to "closed," and the impeller switch (5) to "off." When proper maintenance is available, including external pressurized air supply, the seats are further inflated through the one-way valve to perhaps 1 psi.

Note that the inflated seats are of a limited distention construction, so that they will not balloon with increasing cabin pressure-equivalent altitude. Indeed, the seats would be constructed such that complete loss of cabin pressure would not cause seat failure.

The seat can be made in single, double, or triple widths (places) depending on application. The description of the airstop restraint system above involves system elements which are peripheral to the key elements of this system, i. e., the inflated seat and inflated airbags which provide load isolation and can be rapidly deflated for egress after a crash. Thus, instead of having an impeller, a control inflation gas source and distribution tubes might be provided, perhaps utilizing the ventilation air lines in the vehicle. For vehicles which operate on or near the ground, for which periods of heightened crash hazard cannot be as well predicted, a more rapid and automatic mode of bag inflation is required. Alternate electrical circuits and valve systems might also be used.

IV. ANALYTICAL APPROACH

Using mathematics as the handmaiden of science, our goal in an experimental program is to get some measurements representing the real world, represent possible relationships of these measurements by equations of model systems, use the model to predict additional relationships and possible measurements, and measure again in the real world to refine our model. In this program, we have had only a small amount of analog and digital computer support; our models have therefore been simple. We have particularly been concerned with models of vehicles in crashes, and models of the motion of passengers into the airstop restraint system. This work has barely begun.

We have not searched out the early work on the biomechanics of motion. We note, for example, work by Fisher.⁸² Geertz⁸³ considered a spring model, coupling two masses, in interpreting ejection seat results, noting the possibility of dynamic acceleration overshoot in the body. Although Bierman⁴⁸ does not use equations, his stress in 1946 on the possibilities of load isolation by yielding of the restraints is classic. Bierman notes that aircraft crash accelerations involve a series of peaks superimposed on a generally low continuous value; he urges use of a restraint (by stretching nylon straps) which will not transmit to the body these high frequency (short duration) acceleration events. He states, "In a fatal airplane crash whose duration approaches one second, it is believed that impacts of lethal magnitude are produced during only a brief portion of the total time."

Eiband et al.⁸⁴ present the engine, fuselage, and dummy chest and head accelerations and restraint loads of light aircraft horizontal test crashes into a 55° hill at 42, 47, and 60 mph, a condition simulating a stall-spin crash in which the stopping distance of the passenger compartment is essentially the crumpling distance of the anterior fuselage, the most severe form of crash, equivalent to a rigid barrier crash of an automobile. They do not present mathematical models, but indeed provide the measurements on which such models can be based, as discussed below.

Far more extensive measurements were coming, however, from the rocket track experiments; it is not surprising, therefore, to find Nichols,⁸⁵ Engineer in Charge of rocket sled experiments for Northrop Aircraft Company on contracts with the USAF Aeromedical Field Laboratory of Holloman Air Force Base, New Mexico, in 1954 presenting a spring-mass model representation of body motions under various applied load conditions (square wave, trapezoidal wave, triangular wave, half sine wave). He presents equations for these conditions, but with emphasis on the quite large velocity changes (or acceleration durations) studied on the rocket tracks. An elastic restraint, under long duration loads, does not give the load isolation shown by Bierman,⁴⁸ but shows load overshoot. Hence, Nichols comes to an emphasis that "increased restraint stiffness has merit as a means of minimizing the peak forces applied to restrained subjects," and this emphasis has perhaps led our country to spend far more developing rigid restraints than learning how to utilize elastic restraint, in the way we now present in this

report. By using airbags, the elastic properties can be utilized for load isolation when the expected acceleration conditions involve high frequency (above perhaps 5 cps) events, but by changing air pressure the airbag elasticity can be changed to make them essentially rigid if serious acceleration overshoot conditions might occur. Nichols also presents valuable static and dynamic force-displacement data on harness belts, extending Eiband et al.,⁸⁴ who give only static load data.

The place for controlled yielding for load relief in seat design was clearly recognized by Pinkel and Rosenberg,⁸⁶ a paper we have just seen in writing the final section of this report. These authors come back to Bierman's point of high and low frequency aircraft crash deceleration components, presenting a model of a base pulse onto which is superimposed one or more secondary pulses (spikes) of shorter duration. As the airplane skids to a stop, there may indeed be a series of these higher acceleration periods, with decelerations below 3 or 4 g in between. An airplane with wheels up and sliding on dirt might decelerate at about 4 g, depending on how much structure is torn and digging into the dirt. On concrete this deceleration may be below 3 g. The higher accelerations occur with the initial change of aircraft direction on hitting the ground, subsequent changes of direction due to cartwheeling or hitting ground structures, or changes of ground characteristics. No one of the series of high acceleration pulses may involve a velocity change as large or a stopping distance as small as occurs in typically single high pulse automobile crash deceleration events. This explains why automobile crash accelerations are typically larger than airplane crash accelerations even though the initial velocity is less.

Pinkel and Rosenberg⁸⁶ give in their Table 1 (here revised as to headings and with cargo aircraft omitted) the following model for a transport crash.

TABLE 11

Design Values of Longitudinal Airplane Deceleration Pulses

<u>Change in Aircraft Velocity</u>	<u>Δv, ft/sec</u>			
	<u>50</u>	<u>80</u>	<u>130</u>	<u>180</u>
First base pulse				
Peak g	12	18	20	20
Total duration (sec)	0.20	0.20	0.25	0.30
Rise time (sec)	Sine	0.06	0.045	0.03
Secondary spike (above base pulse)				
Peak g	10	15	20	25
Pulse duration (sec)	0.02	0.03	0.04	0.03

TABLE 11 (continued)

<u>Change in Aircraft Velocity</u>	<u>Δv, ft/sec</u>			
	<u>50</u>	<u>80</u>	<u>130</u>	<u>180</u>
Second base pulse				
Peak g (times as for 1st pulse)	9	9	7	1 (at rest)
Spike (half sine)				
Peak g	8	7	7	-

These are all longitudinal ($-G_x$) loads. They state, "Lateral and rearward decelerations can be assumed to have magnitudes equal to 75 to 50 percent, respectively, of those shown in the table with the same durations..... The decelerations in the vertical direction can be taken to be the same as those shown in Table 1."

They go on to show how the mass-spring model of the seat, for various seat resonance frequencies and strengths, would behave in such crashes, in a manner similar but more elegant than what we have done in modeling airstop restraint performance in model automobile crashes.¹⁵ They go on to build a duplex seat able to sustain the low frequency loads and yield to the high frequency loads, and these results are confirmed in part by swing tests, quite similar to our swing tests. They state without further discussion, "Seat parts above the pedestal are made of air-inflated rubberized fabric. These air-inflated members are reinforced with lightened aluminum structural elements. These elements are shielded from the passenger and others in adjacent seats by the air-inflated members." Apparently, Pinkel and Rosenberg⁸⁶ are in at least a co-lateral "ancestral line" of ideas about airbag restraints, although they do not directly suggest the advantages of using the load yielding characteristics of such air-inflated members.

Preston and Pesman¹⁶ give experimental data on transport airplane crashes and a model of loads for varying angles of aircraft-ground impact. Using their data, we have taken the liberty of further simplifications:

$$\text{Longitudinal load, } G_x = 0.0065 V_{\text{mph}}^\theta \text{ deg}$$

For transport aircraft, the fuselage is of sufficient strength to transmit the load back of the nose crumpling without further attenuation. (For light aircraft,⁸⁴ crumpling progresses back from the nose, transmitting about a constant $-30G_x$, with the duration only varying with the velocity change.) Again, for transport aircraft, in our simplification,

$$\text{Normal load, } G_z = 0.33 V_{\text{mph}} \sin\left(\frac{90}{35} \theta_{\text{deg}}\right) \left(\frac{750 - L \text{ in.}}{750}\right)$$

It was found by Preston and Pesman that the normal load was maximum for a 35° impact. This equation also includes the load isolation provided by tail-swingdown. This approximation of load at position L inches from the nose applies only to L less than 500 inches; back of this, the term is held constant as if L equaled 500 inches. We have not used these aircraft crash models, to be perfected in terms of expected velocity changes along each aircraft axis, in calculating airstop restraint performance, but note them here for future reference. Our recent analytical emphasis has been on the automobile crash models, reported elsewhere,¹⁵ for it is in automobiles that improvements of restraints are most desperately needed, in terms of the number of lives to be saved.

Ryan³⁸ also uses to advantage the spring-mass model, and Aldman⁸⁷ gives additional data on the advantages of the long stretching shoulder straps. But it is the elegant studies of Payne⁸⁸ and Shapland et al.⁸⁹ that have presented refinements of the theoretical approach to restraint analysis.

Grime⁹⁰ uses constant deceleration and half sine models for car crashes. Body motion is treated in a single degree of freedom (spring-mass). Von Gierke and coworkers⁹¹ have been leaders in the multidegrees of freedom representation of body internal motions under vibration and impact. McHenry⁹² has made calculations with a seven degree of freedom nonlinear mathematical model of gross body segment displacements under moderate restraint. His digital computer allows complex waveform passenger compartment acceleration inputs in predicting passenger motions with various restraints. However, he does note, "A (1 - cos wt) appears to represent the fundamental waveform of published vehicle decelerations. . . ." We had independently selected this haversine waveform in developing a car crash model.

Our analytical work has been of the simplest sort. Using the haversine, or $\frac{A}{2} (1 - \cos \frac{2\pi t}{\tau})$ waveform, with peaks and periods taken from experimental car crash data (see Ref. 15) however to account for the observed velocity change, we have presented Table 12 as an analytical model of car crashes under various conditions. Since the haversine model is not as well known, we will present the equations here. For the decelerating car we use

$$(1) \text{ Acceleration } \ddot{x} = \frac{a_{\text{max}}}{2} \left(1 - \cos \frac{2\pi t}{\tau}\right)$$

$$\begin{aligned}
(2) \text{ Velocity} \quad \dot{x} &= \frac{a_{\max}}{2} \left(t - \frac{\tau}{2\pi} \sin \frac{2\pi t}{\tau} - \tau \right) \\
(3) \text{ Distance} \quad x &= \frac{a_{\max}}{2} \left(\frac{t^2}{2} + \frac{\tau^2}{4\pi^2} \cos \frac{2\pi t}{\tau} - \tau t - \frac{\tau^2}{4\pi^2} \right) \\
(4) \text{ Initial velocity} \quad \dot{x}_0 &= \frac{-a_{\max} \tau}{2} = v_0 \\
(5) \text{ Passenger compartment stopping distance} \quad x_{\max} &= \frac{a_{\max} \tau^2}{4} = \frac{v_0^2}{a_{\max}}
\end{aligned}$$

For crash conditions in which all of the initial velocity is not lost during the primary impact period, we replace v_0 by Δv , the part of the crash velocity lost by the rear car, or gained by the front car. Adding dimensional constants, we then have

$$\begin{aligned}
(6) \text{ Impact period} \quad \tau_s &= \frac{2 (\Delta v_{\text{mph}})}{a_{\max, G}} (0.0455 \text{ G seconds/mph}) \\
(7) \text{ Passenger compartment stopping distance} \quad x_{\max, \text{ft}} &= \frac{(\Delta v_{\text{mph}})^2}{a_{\max, G}} (0.0667 \text{ ft G/mph}^2) \\
&= \frac{\Delta v_{\text{mph}} \tau_s}{2} (1.465 \text{ ft/s mph})
\end{aligned}$$

We emphasize that the "passenger compartment stopping distance" is, in general, not directly measurable after an accident, since it includes some anterior car structure crumpling and, for car to car crashes, some travel of the impact interface.

Table 12 presents the constants for our preliminary "Automobile Haversine Acceleration Collision Model" for various crash conditions. This model includes many approximations to the "real world." We use impact periods independent of velocity, and accelerations varying in proportion to velocity. Barrier crashes particularly have accelerations increasing more rapidly than velocities. It can be seen that the aligned car to car crash, with one stationary, has the longest period and lowest acceleration, and the barrier crashes the shortest period and highest acceleration. Note that the head-on both-cars-moving collision has a lower acceleration than the barrier crash--apparently because parts of the cars interpenetrate, with some of each passing beyond the initial impact surface.

TABLE 12

**Peak Acceleration Periods and Passenger Compartment Acceleration Distances
for Various Speeds and Collision Conditions
(Automobile Haversine Acceleration Collision Model)**

			Front Car Stationary		Front Car Stationary (front or)	
	Barrier ¹	Head-On Both-Moving ¹	Left Side Collision ²		Rear Collision ³	
			Rear Car $\Delta v = 0.9 v$	Front Car $\Delta v = 0.7 v$	Rear Car $\Delta v = 0.7 v$	Front Car $\Delta v = 0.6 v$
Car speed 15 miles/hour (v)						
Accel	-15G _x	-14G _x	-11G _x	+9G _y	-6G _x	+5G _x
Period (sec)	0.091	0.098	0.11	0.11	0.16	0.16
Distance (ft) ⁴	1.0	1.0	1.1	0.8	1.2	1.1
Car speed 30 miles/hour						
Marginal or unsurvivable with present structures and lap belt only						
Accel	-30G _x	-28G _x	-22G _x	+18G _y	-12G _x	+10G _x
Period (sec)	0.091	0.098	0.11	0.11	0.16	0.16
Distance (ft)	2.0	2.1	2.2	1.6	2.4	2.2
Car speed 45 miles/hour						
Accel	-45G _x	-42G _x	-33G _x	+27G _y	-18G _x	+15G _x
Period (sec)	0.091	0.098	0.11	0.11	0.16	0.16
Distance (ft)	3.0	3.1	3.3	2.4	3.6	3.3
Car speed 60 miles/hour						
Accel	-60G _x	-56G _x	-44G _x	+36G _y	-24G _x	+20G _x
Period (sec)	0.091	0.098	0.11	0.11	0.16	0.16
Distance	4.0	4.2	4.4	3.2	4.8	4.4

NOTES:

1. For barrier and head-on both-moving collisions, this preliminary model includes no rebound velocity. A 10% rebound velocity might be a better model, but this complicates the equations and so is not used here.
2. After the initial acceleration period, due to inelastic interaction with crumpling, in this model the rear car following a side collision still has 10% of the initial velocity and the front car has attained only 70% of the initial velocity (to the side). The rear car has a greater residual velocity and the front car less, and both cars rotate, if the initial velocity vector is not aligned through the centers of gravity of the two cars.
3. After the initial acceleration period, due to inelastic interaction with crumpling, for this model the rear car still has 30% of the initial velocity and the front car has attained only 60% of the initial velocity.
4. The passenger compartment or seat-base acceleration distance given here may include travel due to car deformation (impact surface stationary) and travel of the car (impact surface moving) during the collision acceleration period. For the rear or side collision, the front car seat acceleration distance represents seat travel which may in various cases be more or less than the front or rear car deformations involved in producing this acceleration.

We have also marked off on this table, a boundary of crash conditions "marginal or unsurvivable with present structures and lap belts only." Note that the 30 mph barrier (tree or bridge abutment) crash is considered marginal.

We have indeed gone on to find in the 1965 Stapp paper that there are indications that half of the people killed in cars are killed at speeds of less than 40 mph, and half are killed with passenger compartment decelerations of less than 20 g.

From curve fitting to dynamic data,¹⁵ we have crudely represented the airstop restraint as a linear system of 1820 pounds per foot, 3 cps resonance, with 22% of critical damping. Neglecting damping, in a manner similar to Eqs (1) to (7), it can be shown that for the sine acceleration function

$$\begin{aligned}
 (8) \quad & \text{Passenger acceleration distance (motion into the airbag)} \quad x_1, \text{ ft} = \frac{\tau_s^2}{4\pi^2} a_{\text{max}, G} (32.2 \text{ ft/s}^2 G) \\
 & = \frac{\Delta v_{\text{mph}}^2}{a_{\text{max}, G}} (0.0667 \text{ Gs/mp}^2) = \frac{\Delta v_{\text{mph}} \tau_s}{2\pi} (1.465 \text{ ft/mp} \cdot \text{s})
 \end{aligned}$$

and

$$(9) \quad \text{Peak acceleration} \quad a_{\text{max}, G} = \frac{2\pi \Delta v_{\text{mph}}}{\tau_s} (0.0455 \text{ Gs/mp} \cdot \text{s})$$

It has been approximately determined for a haversine barrier deceleration function of period 0.091 second acting on a sine wave passenger restraint of period 0.333 second that 90% of the initial velocity would represent the equivalent load acting on the unforced restraint. Then for a model 30 mph barrier collision, in which the passenger compartment moves 2 ft (front end crumpling of the automobile) and experiences a haversine loading of 0.091 second period and $-30G_x$ peak (Table 12), the additional motion into the airbag by the passenger would be

$$(10) \quad x_1 = \frac{(0.9)(30)(0.333)}{6.28} (1.465) = 2.1 \text{ ft}$$

Either by using the spring constant of 11 G/ft or by Eq (12), this airbag displacement gives a passenger acceleration of $-23G_x$, which is less severe than the passenger compartment's $-30G_x$, particularly when the latter is often accompanied by failure of present seat and seat belt supports. But this full-body load isolation is attained at the price of moving 2.1 ft in the compartment. To the extent that the passenger compartment cannot be opened up to allow such large full body controlled displacements without bottoming, a more rigid

restraint at the hips must be used, with the chest airbag essentially as upper body support, providing partial upper body and head load isolation only.

Table 12 shows the conditions for other collisions.

TABLE 12
Barrier Collision (preliminary modeling)

<u>Speed (mph)</u>	<u>Passenger Accel</u>	<u>Compartment Stopping Dist (ft)</u>	<u>Passenger Accel</u>	<u>Passenger Airstop Displacement (ft)</u>
15	-15G _x	1	-12G _x	1.1
30	-30G _x	2	-23G _x	2.1
45	-45G _x	3	-35G _x	3.2
60	-60G _x	4	-46G _x	4.2

It is clear that in terms of this simple modeling of airstop restraint performance, excessive displacements would be required to partially isolate from the higher velocity barrier crashes. To prevent bottoming on surrounding structures, we suggest controlling a bag pressure valve by the car speed, so that if the bag inflation is triggered, the bag will attain a pressure appropriate to the car speed at the time and sufficient to prevent bottoming. But before introducing such complexities, direct experimentation of actual airbag systems in cars would be appropriate. The simple models are too simple. They do not show the down load consequences of the deformable lap belt on the airseat, for example. In addition, we have not yet modeled the "rigid" lap belt with deformable upper body support (airbag) case. If the bag "spring constant" were adjusted to upper body weight such that head motion remained at the airbag displacement values of Table 12, head load isolation would be as shown.

A mathematical description of the passenger and car as a coupled system has been attempted. If the deceleration of the car is a haversine independent of the motion of a passenger of mass M, x_1 and x are the distances of motion of the passenger and car from their positions at initial impact, and k is the spring constant of the linear airbag restraint model,

$$(11) \quad M \ddot{x}_1 + k (x_1 - x) = 0$$

Substituting from Eq (9),

$$(12) \quad M \ddot{x}_1 + kx_1 - \frac{ka_{\max}}{2} \left(\frac{t^2}{2} - \frac{v_o \tau}{2\pi} \cos \frac{2\pi t}{\tau} + v_o t + \frac{v_o \tau}{4\pi} \right)$$

This has the solution of the form

$$(13) \quad x_1 = A \sin \omega_1 t + B \cos \omega_1 t + Ct + Dt^2 + E + F \cos \omega_2 t$$

Hence

$$(14) \quad \dot{x}_1 = \omega_1 A \cos \omega_1 t - \omega_1 B \sin \omega_1 t + 2Dt - \omega_2 F \cos \omega_2 t$$

and

$$(15) \quad \ddot{x}_1 = -\omega_1^2 A \sin \omega_1 t - \omega_1^2 B \cos \omega_1 t + 2D - \omega_2^2 F \cos \omega_2 t$$

The constants of these equations for the conditions of passenger motion into a "linear spring" undamped airbag model and passenger compartment deceleration from velocity v_o with a peak haversine acceleration a_{\max} are

$$(16) \quad \omega_1 = \sqrt{\frac{k}{M}}$$

$$\omega_2 = 2\pi/\tau$$

$$A = 0$$

$$B = -\frac{v_o \tau}{4\pi^2} + \frac{a_{\max}}{2\omega_1^2} - \frac{\omega_1^2 v_o \tau}{(\omega_2^2 - \omega_1^2) 4\pi^2}$$

$$C = v_o$$

$$D = \frac{+a_{\max}}{4}$$

$$E = \frac{v_o \tau}{4\pi^2} - \frac{a_{\max}}{2\omega_1^2}$$

$$F = \frac{\omega_1^2 v_o \tau}{(\omega_2^2 - \omega_1^2) 4\pi^2}$$

These values may be used to evaluate the motion of the passenger with respect to the airbag at $t = \tau$, the end of the passenger compartment deceleration, to provide the initial conditions of the further free response of the unforced airbag system. However, at this point we can also easily introduce airbag damping. (More complex models, with damping from time 0, could of course be

handled by computer; we have not yet done this.) Our preliminary experience is that airbag damping, even without special internal baffles etc., is about 11% of critical damping for the bag alone, and 22% for the bag with airseat and seat belts; this latter value is used for the model presented here. The response of the passenger-airbag system at time t after the car stops is thus given by

$$(17) \quad x_1 = e^{-\beta t} (A \sin \theta t + B \cos \theta t)$$

$$(18) \quad \dot{x}_1 = e^{-\beta t} (A \theta \cos \theta t - B \theta \sin \theta t) - \beta e^{-\beta t} (A \sin \theta t + B \cos \theta t)$$

$$(19) \quad \ddot{x}_1 = e^{-\beta t} (-A \theta^2 \sin \theta t - B \theta^2 \cos \theta t) - 2\beta e^{-\beta t} (A \theta \cos \theta t - B \theta \sin \theta t) + \beta^2 e^{-\beta t} (A \sin \theta t + B \cos \theta t)$$

For our case, with time now measured from the end of the car stopping period τ which gives the initial conditions for Eqs (20) to (22), the constants are

$$(20) \quad A = \frac{\dot{x}_1, \tau}{\theta} + \frac{\beta}{\theta} (x_1 - x)_\tau$$

$$B = (x_1 - x)_\tau$$

$$\theta = \sqrt{\frac{k}{M} - \beta^2}$$

$$\beta = C/2M$$

$$C = (\% \text{ of critical damping}) 2 \sqrt{Mk}$$

Note that with the airstop restraint, the rate of change of acceleration is reduced over the "jolt" effect of the lap belt. For a haversine function of a_{\max} acceleration peak and period

$$(21) \quad \ddot{x}_{\max} = \frac{\pi a_{\max}}{\tau} \text{ (in G/s)}$$

For a lap belt 50G peak of 0.055 second period, the "jolt" effect of the lap belt becomes

$$(22) \quad \ddot{x} = \frac{(3.14) (50)}{0.055} = 2850 \text{ G/s,}$$

a value which can contribute to the injury due to internal resonances. The airbags smooth out the load applied to the passenger, and distribute it over the entire body surface, so that with airbags (not bottoming) the load would be more tolerable even if of the same amplitude as the lap belt load. Our problem

then is to prevent passenger "bottoming" through the airbags or airseat onto rigid or sharp surrounding structures. If bottoming can be prevented, the airstop restraint appears in this simple theoretical analysis to be very effective in reducing passenger injury and death in automobile crashes.

If cars can be modified to allow controlled displacement of the passenger during deceleration, without bottoming, load isolation by the airstop restraint can be utilized to prevent injury for crash conditions which now are fatal. If the cars cannot be modified, or bottoming might occur, we suggest using chest airbags at higher pressure, increased automatically proportional to speed after impact but just before the body begins to move, since bag pressures above 10 inches of water are uncomfortable prior to deceleration, and also using a wide belt (3 inches or more) on a more rigid lower seat structure (high pressure airseat base), with the airseat back and chest airbag as the controlled deformation members for upper body support.

Analyses of longer duration loads, such as in rear end collisions, show that one reaches a condition in which the load on a passenger in an airstop restraint is indeed greater than the load on a passenger in a rigid restraint (though less than the load on an unrestrained passenger or one with a lap belt only). For such conditions, we suggest that the preloading provided by increasing bag pressure proportional to vehicle speed just after impact but before the body begins to move (0.03 to 0.05 second after impact) will significantly reduce this overshoot. We conclude with McHenry⁹² that the "softest" deceleration is the one that uses (in the right time phasing) the maximum amount of available passenger motion.

We present the airstop restraint as one whose characteristics can be actively adjusted to ensure this optimum restraint.

Airbag restraint systems, including the airstop restraint with chest and perhaps foot airbags and airseat, obtain their acceleration isolation qualities, for acceleration events with frequencies above about 4 cps for present systems, by controlled motion of the subject with respect to the vehicle. For lower frequency acceleration events, airbags cannot reduce the acceleration on the subject, but it is emphasized that these low frequency events generally involve low and quite tolerable accelerations to account for the required g seconds of velocity change of the event. We can tolerate the low frequency components; it is the high frequency components with amplitudes above perhaps 20 g that we would like to eliminate with our restraint.

For sinusoidal vibrations of frequency f , in cycles per second, and peak acceleration a , in g units, the double amplitude of displacement d in inches is given by

$$(23) \quad d = 2 a g / 4 \pi^2 f^2 = 19.7 a / f^2.$$

The goal of the elastic restraint is to allow the subject to stay still (i.e., move along the mean vehicle flight path) while the vehicle vibrates about him. This "decoupling" from the vehicle vibration will require an allowable distance of body motion with respect to the vehicle of rather more than d , since it is difficult to obtain perfect decoupling, and "bottoming" at the end of the elastic restraint stroke must be avoided.

At resonance, with a continuous vibration input, elastic restraint systems can store energy and eventually deliver a greater load to the subject than any individual vibration peak. For our astronaut airbag restraint, damping was about 11% of critical damping, or about 50% amplitude attenuation per cycle, so that a sinusoidal loading at the resonance frequency would build up to a body load of 4.8 times the applied loading. For impact loading (i.e., single half cycle) at resonance frequency, the overshoot is much smaller. Indeed, we now suggest what has perhaps been a heresy in acceleration work that a certain amount of resonance overshoot at a low resonance frequency is quite acceptable if this restraint eliminates at the same time the high acceleration high frequency components. Perhaps some have been dissuaded from considering elastic restraints by an over-concern for the rebound problem. It is not the rebound loads that we must avoid, for these can be at a physiologically quite acceptable frequency and generally of acceptable amplitude. We are concerned to avoid the bottoming loads at the travel limits of our restraint.

For impacts of velocity v imposing a square wave tolerable load a on the subject, the stopping distance d of the subject is given by

$$(24) \quad d = v^2 / 2a \quad g \text{ (square wave time history)}$$

To the extent that the vehicle stops other than instantaneously, the body motion with respect to the vehicle would be decreased. A practical system does not provide a square wave load, a circumstance reducing concern for onset rates of change of acceleration. For a sine wave load (i.e., a simple harmonic motion elastic restraint excited by an initial velocity at the rest position), a stopping distance twice as great as that for the square wave load case is required.

$$(25) \quad d = v^2 / a \quad g \text{ (sine wave time history)}$$

This distance then determines the elastic properties required:

$$(26) \quad \frac{K}{M} = \frac{ag}{d} ; \quad f_n = \frac{1}{2\pi} \sqrt{\frac{K}{M}} \quad \text{(resonant or natural frequency)}$$

The ideal elastic restraint would use the entire available stopping distance within the vehicle, for a given impact velocity, to give a minimum subject acceleration. This would require the ability to change the properties of the

elastic restraint for each acceleration event of concern. It is indeed this flexibility of changing elastic properties by pressure change that is so attractive for airbag restraint systems, which has led us to call airbag restraints "active elastic restraint systems," as opposed to passive elastic restraint systems such as cushions and springs whose elastic properties cannot be changed.

Airbag restraint systems may not be simple harmonic motion systems, with a linear force-displacement curve, although this approximation of the properties of distensible airbags of latex for example, is quite good. For the indistensible wall case if the bags are represented by a model of a piston of body area A moving into a cylinder of initial volume V_1 and pressure p_1 , under adiabatic conditions, then

$$(27) \quad p_2 = p_1 (V_1/V_2)^\gamma$$

where γ for air is about 1.4. Then since we have

$$(28) \quad p_2 A = Ma g, \text{ and}$$

$$(29) \quad V_2 = V_1 - Ad, \text{ we can write}$$

$$(30) \quad a_1 = \frac{p_1 A}{Mg} \left(\frac{V_1}{V_1 - Ad} \right)^\gamma$$

Note that at the rest position there is a restoring force $p_1 A$ which must be balanced either by the weight Mg or by an opposing airbag or seat.

Know the available stopping distance d , body mass M , body area A , initial bag volume V_1 , and initial pressure p_1 , one can then compute the peak acceleration a , in g units, for this bag compression. Note that the pressure p is absolute pressure, so that one atmosphere must be added to the "few inches of water pressure" which we utilize.

In actuality, this adiabatic piston model is quite inadequate for body displacements into real airbag restraint systems. As the subject moves into the bag under acceleration, the bag can bulge to the sides or around him. Hence, the effective area being decelerated by the bag pressure becomes greater than A and the volume change for a given displacement can be reduced. This tends to flatten the force-displacement curve. Indeed, in our work we have not measured bag pressures at impact as high as 2 psi above atmospheric, well below the pressures predicted by an adiabatic piston model.

Moreover, to the extent that the bag walls are distensible, the force-displacement curve is further flattened, and indeed with the latex bags the linear force-displacement model is a reasonable fit to the experimental data.⁷⁷ In an attempt to make analyses, we assume that the bag wall distensibility is not important for small displacements and with greater possible approximation, that the deviations from the adiabatic piston model are small for small displacements. We then can evaluate the slope of the acceleration-displacement curve (Eq (30)) for the adiabatic piston model.

$$(31) \quad \frac{da}{dd} = \frac{\gamma A^2 p_1 V_1^\gamma}{Mg (V_1 - Ad)^{\gamma+1}} \quad \text{Then at } d = 0$$

$$(32) \quad \left. \frac{da}{dd} \right|_{d=0} = \frac{A^2 p_1^\gamma}{Mg V_1}$$

A property of the simple harmonic motion elastic restraint is that the acceleration-displacement curve, the velocity-displacement curve and the acceleration-velocity curve are linear:

$$(33) \quad \frac{da}{dd} = \frac{K}{Mg}, \quad (a \text{ in } g \text{ units})$$

$$(34) \quad \frac{dv}{dd} = 2\pi f_n = \sqrt{\frac{K}{M}}$$

$$(35) \quad \frac{da}{dv} = \frac{1}{g} \sqrt{\frac{K}{M}}$$

These relationships may be readily determined experimentally, particularly, Eq (35) since this avoids the direct measurement of displacement. Hence from Eqs (32) and (33), for the simplified adiabatic piston model,

$$(36) \quad K = Mg \frac{da}{dd} = \frac{A^2 p_1^\gamma}{V_1}$$

and from Eqs (32), (33), and (35) for the simple harmonic model

$$(37) \quad K = Mg^2 \left(\frac{da}{dv} \right)^2$$

Evaluating these for the pilot compartment airbag system for Fig. 32, and its dynamic performance as given in the acceleration-velocity Fig. 48 of Ref 77, we find

$$(38) \quad K = \frac{(1.4 (11))^2 (2150)}{98} = 3720 \text{ lb/ft}$$

for the simplified adiabatic piston model, and

$$(39) \quad K = \frac{265}{32.2} (32.2)^2 (0.5)^2 = 2130 \text{ lb/ft}$$

for the rough experimental fit to the simple harmonic model of the same restraint.

It can be seen that the adiabatic piston model, even evaluated at zero displacement, predicts a system almost twice as stiff as is predicted from the experimental results with latex airbags. Work is continuing to improve the model to allow the prediction of the optimum design and behavior of any airbag restraint system.

V. FURTHER APPLICATIONS

A. PALLETIZED AIRSEAT

The airseat has demonstrated its impact protection capability when used without the chest airbags (the C-45 Crash Test of April 1965). This and the capability of being deflated to the floor for ease of emergency egress from the aircraft lend themselves to the use of the airseat in a palletized version. This would allow rapid change from passenger to cargo configuration and any combination of intermixing of passengers, stretcher cases, and cargo.

Flat pallets, no more than 12 in. thick, could be designed to contain deflated airseats in any combination of abreast seating. Each seat or seats would be folded within a cavity in the pallet and concealed by a fold-down panel. The pallets, when installed in the aircraft with the seats still deflated, would provide a clear cargo area with all the normal cargo tiedowns incorporated into the pallets. At any time while on a flight route the mix could be adjusted by selectively inflating just those seats necessary. All-cargo to all-passenger load changes would be simply a matter of inflating or deflating and stowing the seats. This system could be permanently designed into the aircraft except for the case when maximum payload capability for cargo is required, necessitating removal of the palletized seats.

Design of the palletized airseat would include the following:

- (1) A pallet structure to house the deflated airseat assemblies with appropriate covers providing normal cargo floor loading capabilities and tiedown provisions.
- (2) Connections for inflation from engine compressors, ventilation blowers, or external air supply.
- (3) Manual and individual deflation provisions for rapid conversion.
- (4) Airseats constructed of limited distention materials such that when inflated they will feel and look like an ordinary seat but still provide the controlled displacement qualities for impact protection.
- (5) Provisions for automatic deflation after an impact situation to open the entire cabin as an escape corridor.

B. LIGHT PLANE EMERGENCY RESTRAINT

A small, portable, self-contained, single use type chest airbag system is envisioned for use in the light plane, prior to such time that the full airstop restraint can be built into such aircraft. In each passenger position, the unit

would be secured to the seat back or instrument panel in front of the occupant. A single electrical plug connection from all units leading to a switch that would be controlled by the pilot might be utilized, or each occupant might control his own airbag.

To provide protection for the pilot and co-pilot by inflating airbags without affecting their flight control, it will be necessary to eliminate the control wheel or center stick. This function can be replaced by the now familiar side arm controllers of high performance aircraft and spacecraft. A simpler modification might be to replace the pilot's and co-pilot's seats by the airseat (or indeed a rigid high back seat) with shoulder straps, with only the passengers having chest airbags.

Design of the light aircraft system would include the following details:

- (1) A lightweight transparent airbag, possibly of elastomeric vinyl, designed for a single inflation and impact event with a manual deflation tear-gore.
- (2) A styrofoam, fiberboard, or lightweight plastic case with the airbag inflation port(s) for containing the packaged airbag, and provision for securing to the instrument panel or seat backs.
- (3) An inflation bottle (air or CO₂) with valve and electrical connection contained within the case.

Inflation would be initiated by the pilot or passenger with the bag deploying in about 1 sec, possibly through a frangible section of the case. Deflation after the impact or after landing if the emergency did not develop would be manual by each person, either by a plug or tear open provision. The entire unit would be relatively inexpensive and would be replaced after being activated whether used for impact protection or only as a safety precaution.

C. AUTOMOBILE EMERGENCY RESTRAINT¹⁵

With the historical tendency of increasing distances of travel, distance death and accident rates must decrease in order to have a constant probability of survival per trip or travel day. With 140 deaths and some 5600 injuries (sufficient to prevent activities the next day) per day on United States highways, today's probability of survival is clearly inadequate: distance death and accident rates must be reduced even faster than travel distances increase. We suggest an increasing Federal expenditure for safety research, initially of at least an order of magnitude, and for safety applications, with annual increases at least until such time that the total numbers killed and injured each year no longer increase, and indeed decrease. We expect that the total cost to society of highway crashes plus increased safety research plus increased safety applications will actually be less than today's horrendous cost of crashes alone--some nine billion dollars per year.

Lap belts alone, in today's cars, are not sufficient restraint. The 30 mph barrier crash, even with lap belts and seats that do not fail (as far too many would) is probably fatal. Even the 20 mph barrier crash, giving about 20G at the passenger compartment, would probably be fatal with far too many of our cars. Upper body support and seats which do not fail to at least 30G must be added to reduce death and injury in our cars.

Analytical examination and experimental crashes in aircraft and crash simulator devices (but not yet in automobiles) indicate that excellent additional protection would be provided by the airstop restraint. This consists of an inflated airseat, which in design looks and feels like an ordinary seat at 1G and has the inflation reliability of the automobile tire but under higher acceleration loads controllably deforms without failure to over 30G, and a transparent chest airbag automatically inflated in 0.25 sec to 0.1 to 0.3 psi if abnormal car behavior, or later remote highway sensing devices, indicate that a crash situation might develop. If an actual crash impact occurs, this would be sensed, releasing additional pressure perhaps to several psi in proportion to speed into the chest airbags to reduce the chances of bottoming through the bags. Perhaps five seconds after impact, airbag and airseat pressure would be dumped, facilitating escape from the car. We note that we have done no work yet on high speed bag inflation, although we understand that others have, nor have we experimentally examined the limits of steering, braking, wheel vibration and other abnormal car behavior which we would detect to automatically trigger airbag inflation.

Until such time as car controls are modified, we suggest that drivers not be restrained by inflating airbags, which might contribute to the severity of the developing crash, but by lap belt and shoulder straps, and a rigid seat able to withstand over 30G. The inflating airbags "grab the wife and kids," even those playing or sleeping totally unrestrained on the open floor in the back of a station wagon, and push them into a restraint position, protecting them from the crash. Children would be adequately protected by the airbags alone up to speed limits. With the limited clear volume for controlling motion before hitting surrounding structures in our automobiles, heavier adult passengers should be additionally restrained by wearing a lap belt on the airseat wherever high speed driving is done. We suggest inspection (perhaps automatically) at the start of all high-speed roads (speed limits above 40 mph) with the prevention of high-speed driving by all those without adequate restraints. A start toward this could be made on all our toll roads today; if every driver and passenger do not have seat belts in use (or a certified airstop restraint system ready for use) the car should not be allowed on the high-speed road.

To reduce the severity of side crashes, we suggest first reducing the penetration of the striking car (or tree) into the struck car passenger compartment by adding a strong side bumper inside a crushable outer door structure. This structure would allow some car interlocking in a side impact, attenuating loads and reducing roll-over of the struck car, but without the penetration that now accompanies these effects. This side bumper would

interlock with car structure front and back when the door is closed, preventing door opening except on purpose. On sensing an impact load, we suggest inflating airbags over the side windows in 0.03 sec to reduce head loads and glass penetration.

The airseat, with its transparent section above shoulder level, provides rear collision protection, supporting the head and back by controlled yielding. The chest airbag prevents rebound injury.

Preliminary analysis indicates that half of the automobile passenger fatalities occur with passenger compartment accelerations of less than 20G¹⁵. With improved restraint, either lap belt and shoulder strap and seats which do not fail to over 30G or the airstop restraint, this death toll could, in preliminary view, be at least cut in half. The airstop restraint has the additional advantage of providing protection even though the passenger has not taken the special safety step such as attaching belts and straps required for other restraints. The airbags inflate automatically whenever the car enters a potential crash situation.

Figure 114 shows a mockup of an automobile restraint system, with a transparent chest bag but without the high back airseat.

Automobile experimentation is essential to extend this preliminary analysis of the potential of the airstop restraint. Many problems for research remain, including the quantification of the automatic signals triggering airbag inflation prior to a crash, engineering of the system for the car, materials and reliability analyses, passenger acceptance, and experimental validation of the protection provided in actual automobile crashes.

Figure 115 shows how a prototype safety car might look. This car incorporates the chest airbag restraint for longitudinal impact isolation, inflatable side window airbags for side impact head protection, permanently inflated airseats and inflated lower door panels. The car is shown after automatic airseat inflation following sensing of a potential or actual crash situation.

Other car safety considerations are noted. 98-109

D. HIGH-SPEED TRAIN EMERGENCY RESTRAINT

An inflatable restraint system for the 200 mph train of the future would be configured very similar to that of the aircraft type system since the train seating configuration will be quite similar. With the train, however, the sensing of an impending impact situation is quite straightforward. The majority of accidents will involve derailment prior to the impact event--sufficient time for rail sensors to actuate the airstop restraint system. The seated passenger restraint coupled with aspects of the "softpack" system (see Section E of this chapter), inflating bags from wall, ceiling, and aisle compartments, would provide impact protection for the standing and walking as well as seated persons.

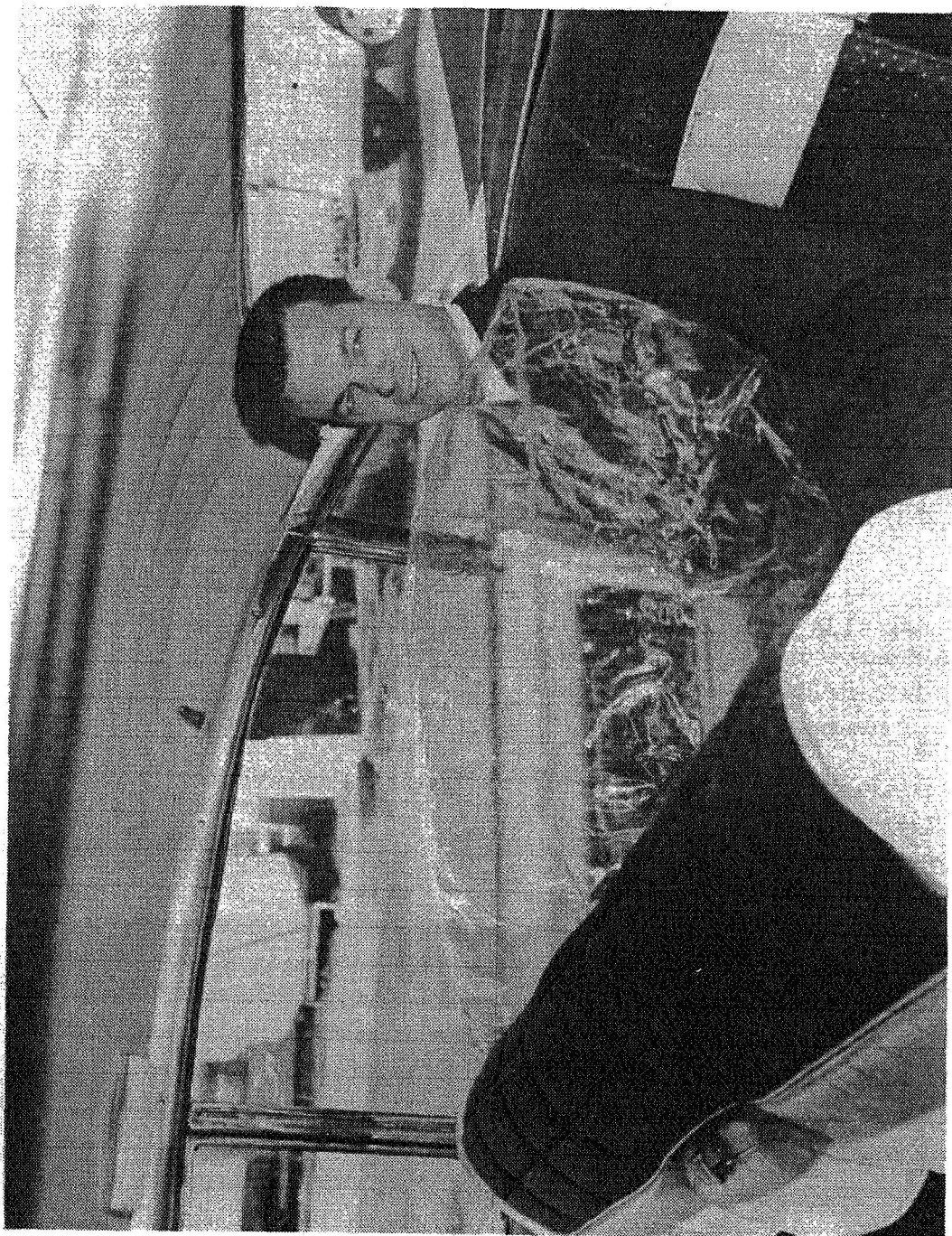
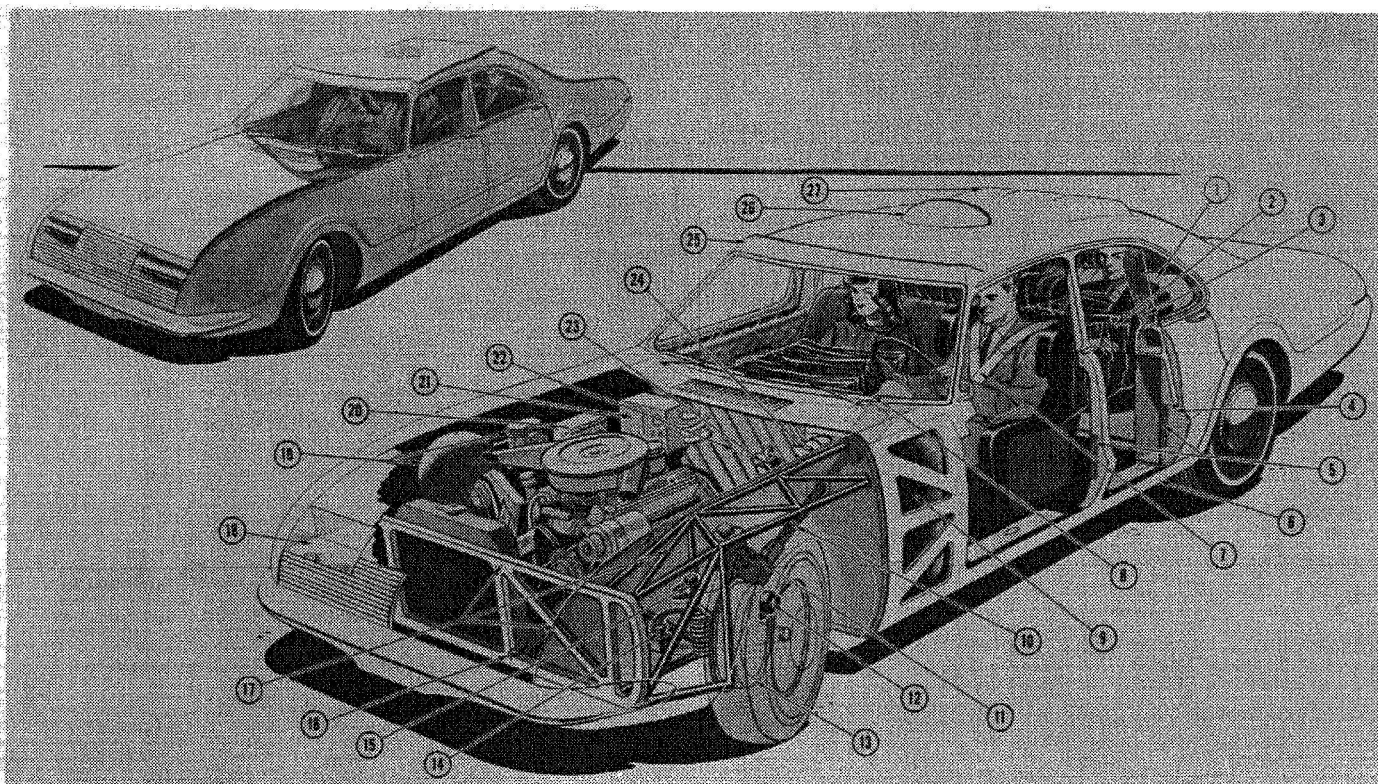


Fig. 114. Mockup of an Automobile Airstop Restraint



- | | |
|--|---|
| 1 Airseats with transparent upper seat backs adjustable back and forth by selective inflation | 14 Hydraulic system pressure transducer |
| 2 Airstop airbag for passengers, shown inflated | 15 Wheel bounce acceleration transducer |
| 3 Side window inflatable airbag for side crash protection | 16 Bumper impact airbag inflation sensor time delayed for automatic bag and seat deflation |
| 4 Safety door structure | 17 Crash designed structure around engine compartment (energy absorbing) |
| 5 Door safety locks | 18 Prismatic projection headlight for smooth body contours and pedestrian impact protection |
| 6 Unitized passenger compartment | 19 Fire suppression system |
| 7 Restraining lap belt and shoulder harness for driver in Crandell seat design | 20 Electronic abnormal auto behavior package |
| 8 Dashboard eliminated except for driver controls and display (all fixed displays could be eliminated by driver selection of "Heads Up" projection). The car radio would also receive automatic roadside directions and warnings | 21 Airbag inflation-deflation mechanism |
| 9 Pressurization tank | 22 Engine deflecting firewall |
| 10 Collapsible and flexible steering shaft | 23 Automobile speed transducer |
| 11 Power steering | 24 Steering column position and rate transducer |
| 12 Wheel rotation rate transducer | 25 Rear view projection system |
| 13 Power brakes | 26 Closing rate laser radar |
| | 27 Safety taillight-flasher system |

Fig. 115. Safety Car

E. "SOFTPACK" RESTRAINT

The softpack personnel restraint system has applications when personnel, civilian or military, must be carried in transportation vehicles, ground or air or space, when regular seats are not available or their use would limit equipment carried by the personnel.

In the paratrooper application (Fig. 116), the troops, with all hand-carried equipment, would enter the aircraft and the softpack airbags would be inflated about them as they get in place. These bags would support the men and all carried equipment, so that the men would relax in place yet have all their equipment right at hand when the softpack bags are deflated. We have tried this, relaxing upright in inflated airbags with one subject; he felt he could easily go to sleep on his feet. In case of either forward or down crash loads, the bags would provide significant load isolation. At jump time, the bags would be deflated in sequence from the jump door, allowing a clear cabin volume and rapid egress. In case of a crash, the bags would be automatically deflated after the vehicle comes to rest, again aiding rapid egress.

F. HIGH-SPEED OFF-ROAD MILITARY LAND VEHICLE RESTRAINT

As the speed and maneuverability of combat vehicles increase, the crew is subjected to more potentially violent vibrations and impacts. There is a need for a corresponding improvement in seating restraint and load isolation.

The application of the airbag restraint technology to the combat vehicle was examined as one of several potential improvements over present combat seats.⁹³

A very crude mockup of a vibration load isolator seat was made (Fig. 117), using available airbags, and mounted on a shake table. Resonance was found at about 1.7 cps, a frequency we feel could be further lowered by appropriate bag design. Load transmissibility (acceleration of the subject's hip to that of the shake table) was down to 0.3 by 5 cps and 0.12 by 8 cps. Secondary resonances with this crude system occurred near 23 and 36 cps, but transmissibility remained below 0.25 even at these resonances. Since a great deal of the vibratory energy of off-road military vehicles is at frequencies above 5 cps,^{94, 95} we feel that there is promise in this load isolation by a dynamic restraint system such as the airbags, whose restraint characteristics can be varied by adjusting pressure for the particular ground and speed conditions. Such a restraint system could, we feel, significantly reduce the present medical complaints of military motor vehicle crews. We lost the competition for the commander's seat design for the Army Tank Automotive Center and have done no further work on the concept. However, the sketches developed are briefly presented here.

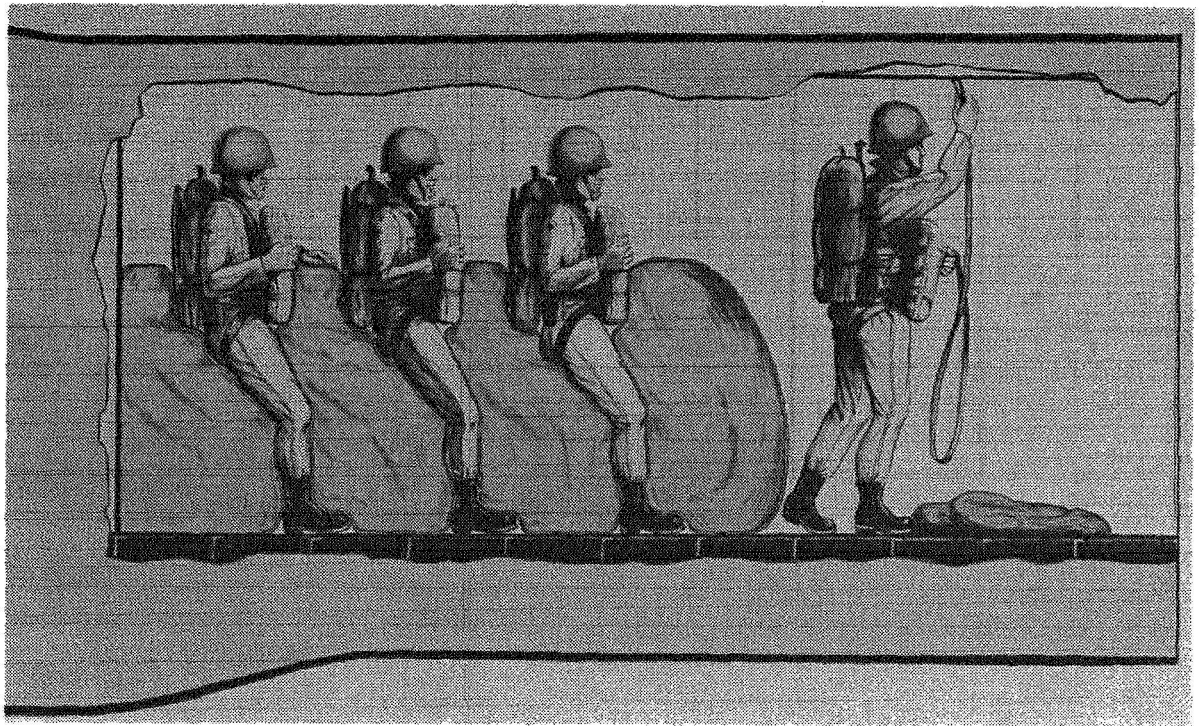


Fig. 116. Soft Pack Restraint-Paratroop Configuration

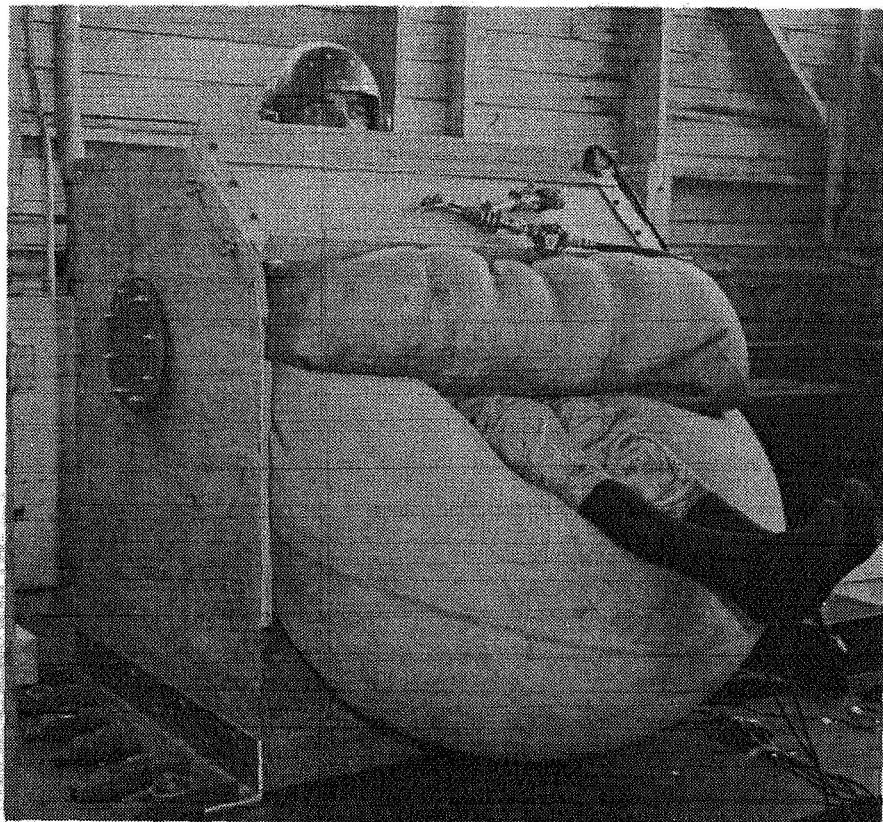


Fig. 117. Vibration Test of a Crude Land Vehicle Airbag Restraint

Figures 118 and 119 show an adjustable fiberglass seat with an internal airbag restraint including elements for active massage with periodic load displacement, and load shifting with selective load displacement. Airbag use does require that the restraint be not just 1 or 2 in. of passive padding, but that it be thick enough to prevent bottoming under acceptable pressurization for the loads contemplated. Preliminary analysis is that 6 to 8 in. under the man's buttocks would be utilized. In previous work, bag pressures of 3 to 10 in. of water were used, with higher pressures available when limited distension ribbons were used in the bags. An important feature of the airbag restraint design is that it may be readily adjusted for its motion environment, and the upper bag is readily depressurized to get out of the way when the vehicle is at rest.

A modular commander's station was also examined considering the restraint of the commander as part of the overall integrated command system and not necessarily as a separate function.

Maximum protection from harmful induced environments can best be accomplished by incorporation of airbag (in special cases, fluid bag) encapsulation. This technique will allow the commander to be isolated from vehicle induced accelerations and vibrations. Vehicle noise, heat, and fumes will be reduced or eliminated. Metal thicknesses of the capsule case plus 8 to 10 in. of airbag or fluid bag completely surrounding the commander would be sufficient isolation from shrapnel, fire and radiation (combat environment) to ensure continuous command operation. The most economical (in weight and size) protection is individual encapsulation (see Figs. 120 and 121).

Certain ballistic protection tradeoffs could be effected, thus reducing overall vehicle weight. The incorporation of the dead air, fluid space, and reflective surfaces would protect the occupant from most fire hazards, or, at least, protect him long enough for other escape means to be activated. CBR protection could be accomplished with a minimum of additional material. Vehicle fluids (water or fuel) could be pumped into the airbags for protection from neutron radiation; the metal shell could protect from gamma exposure. A closed loop air supply system would supply the commander under completely closed environments.

Forty-eight hours of habitation would be accomplished in one position: standing or, more correctly, supported vertically within the airbag support system. Preliminary tests indicate this to be feasible, and that one in fact can relax into the vertical restraint system so completely that sleep appears possible. Advantages of this position are twofold:

- (1) Minimum circumference during 360 deg of rotation.
- (2) Constant relationship is maintained between the commander and his functional controls. (There is no shift of the man between two separate duty stations and no loss of command functions, i.e., target identification, ranging and surveillance and antipersonnel defense.)

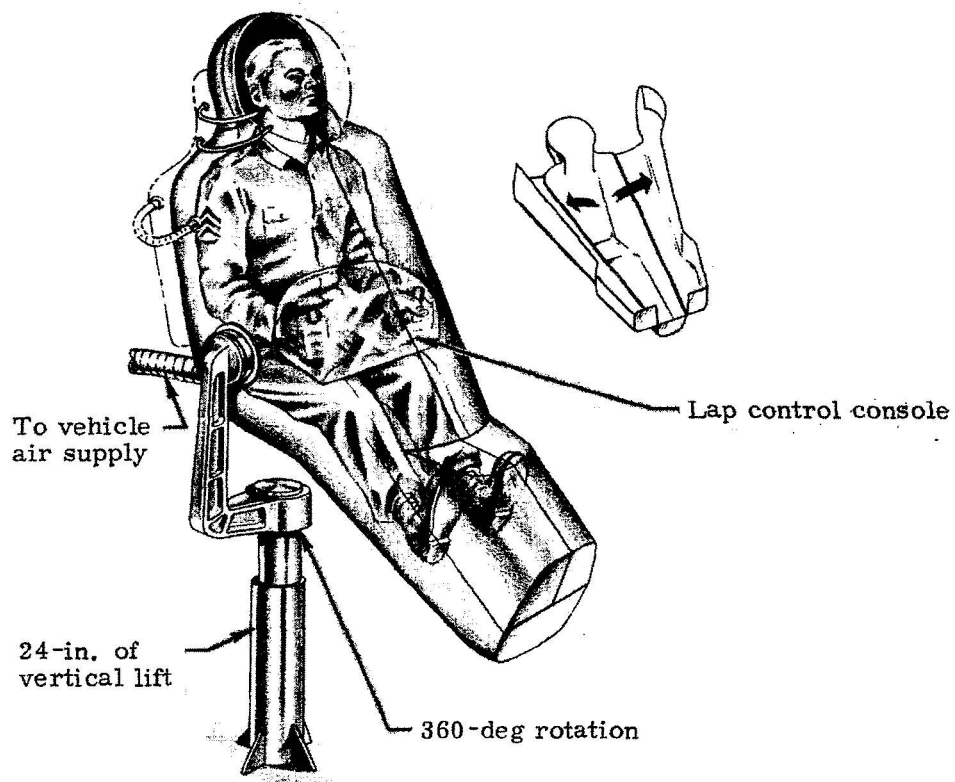


Fig. 118. An Advanced Fiberglass Airbag Restraint Commander's Station

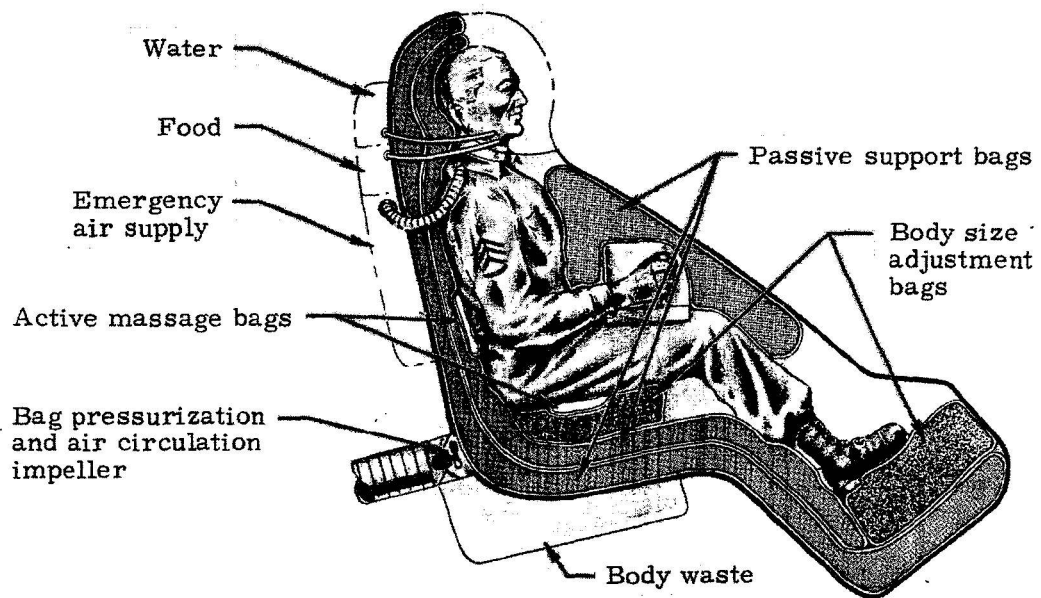


Fig. 119. Sectional Detail of the Fiberglass Airbag Seat

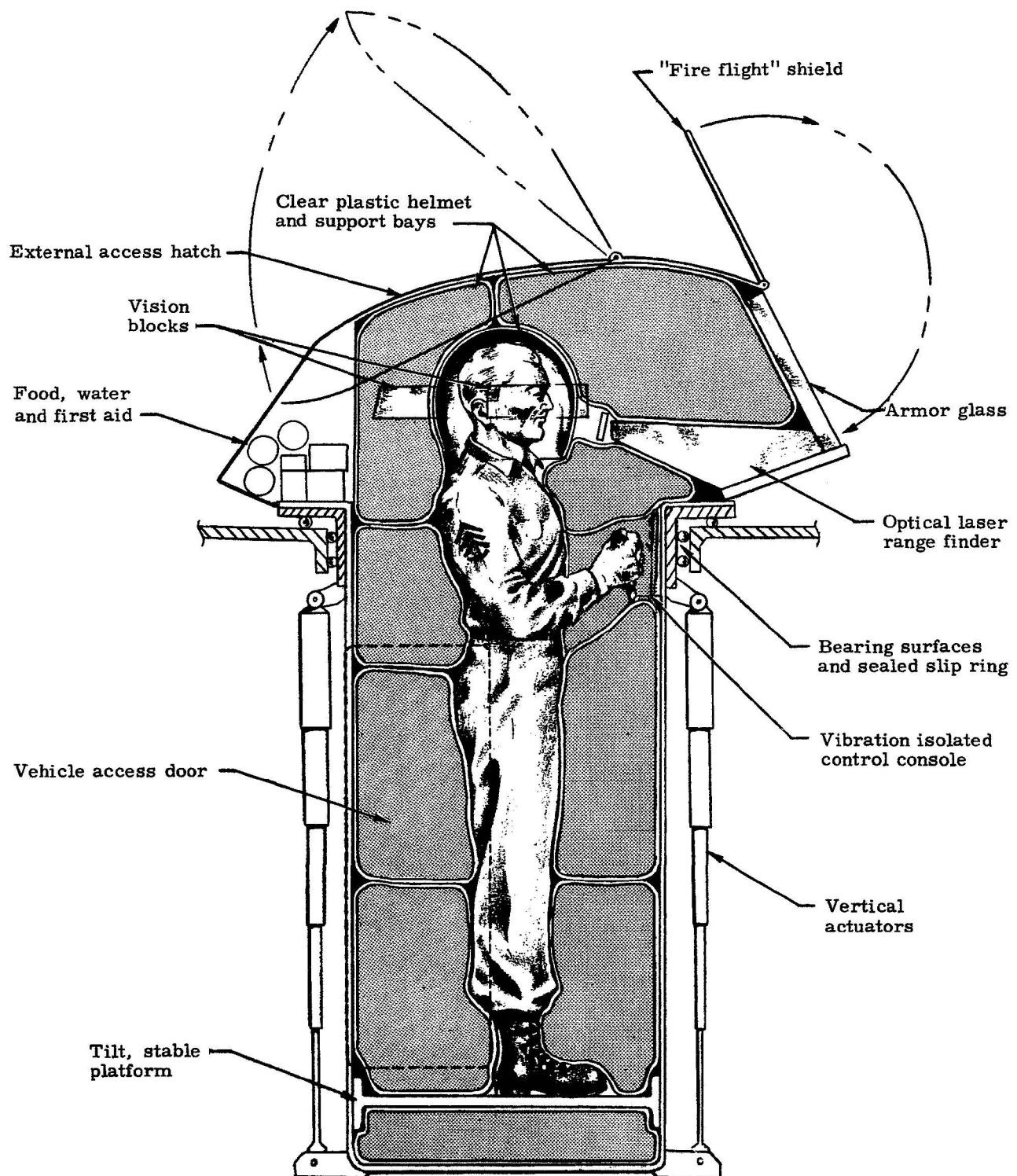


Fig. 120. 48-Hour Command Module in the Elevated Position and Sectional View

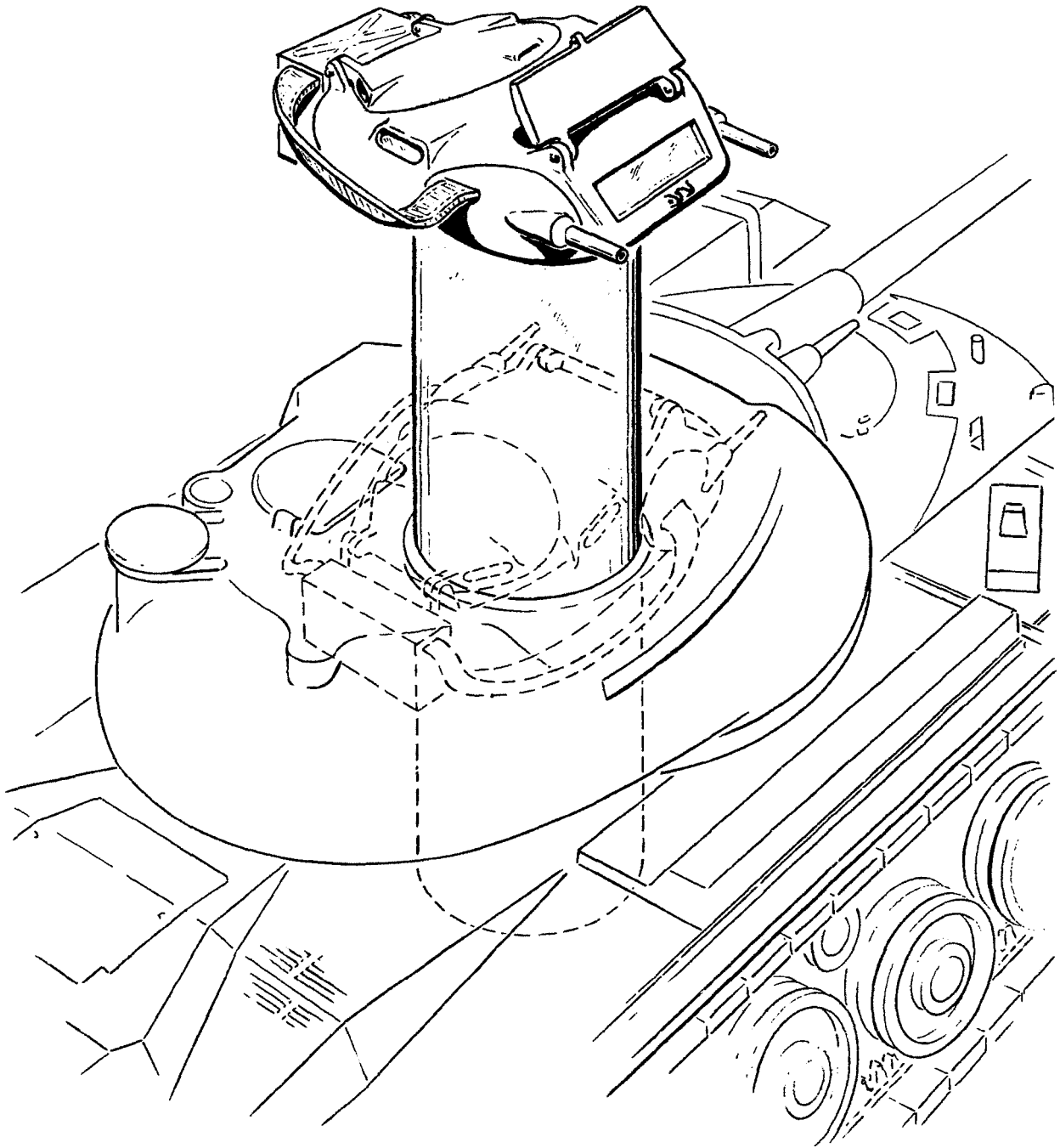


Fig. 121. 48-Hour Command Module (elevated position)

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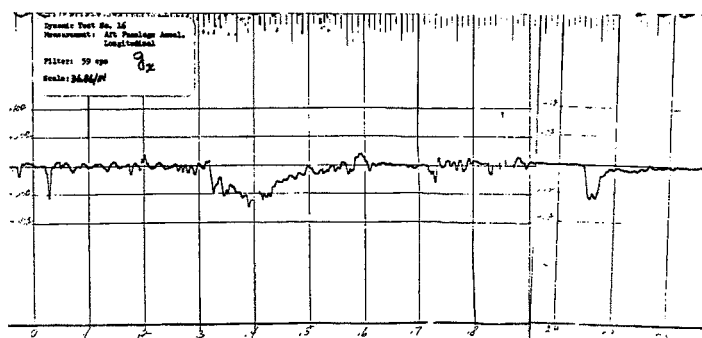
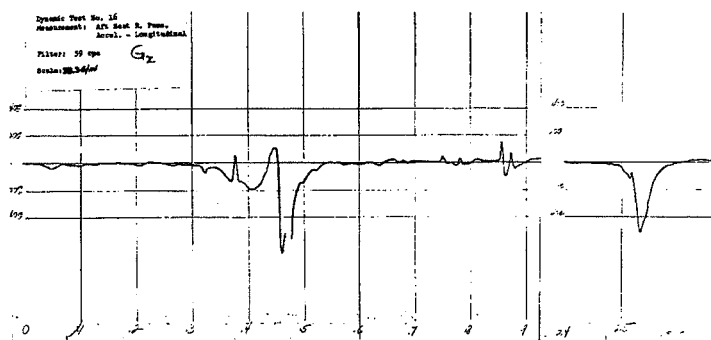
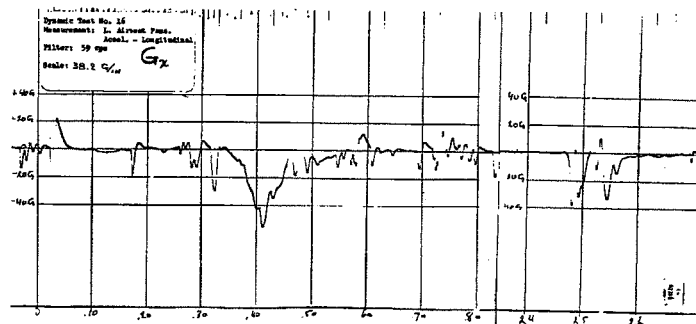
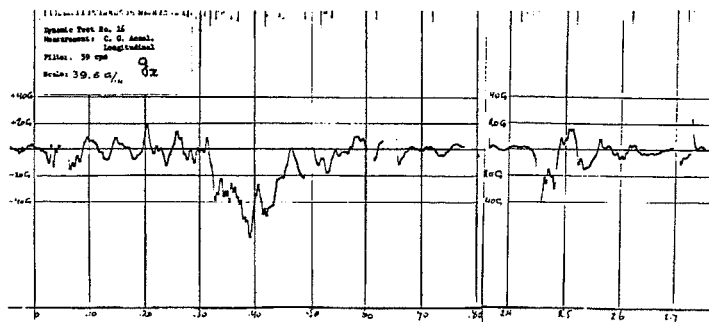
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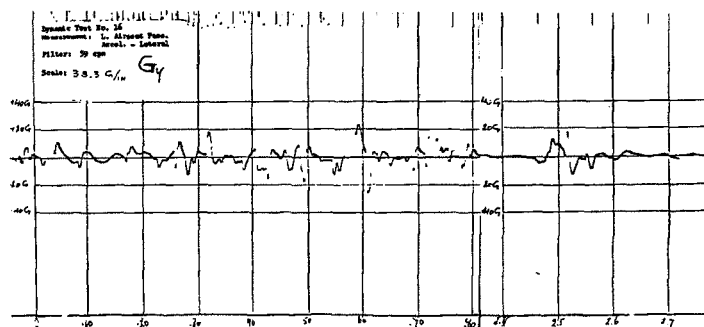
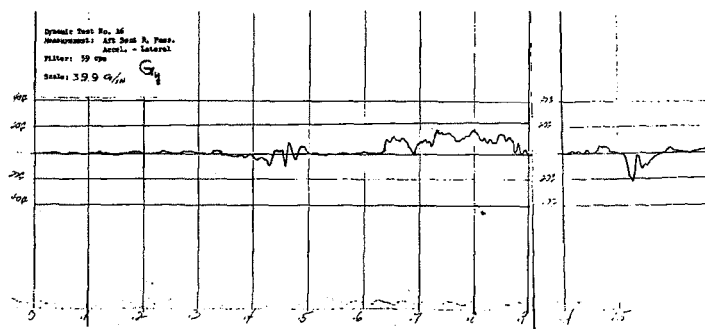
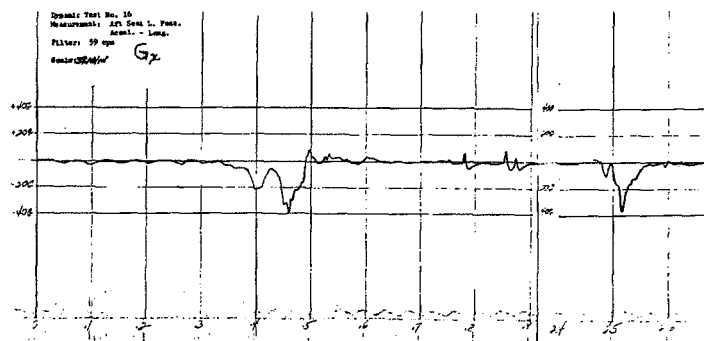
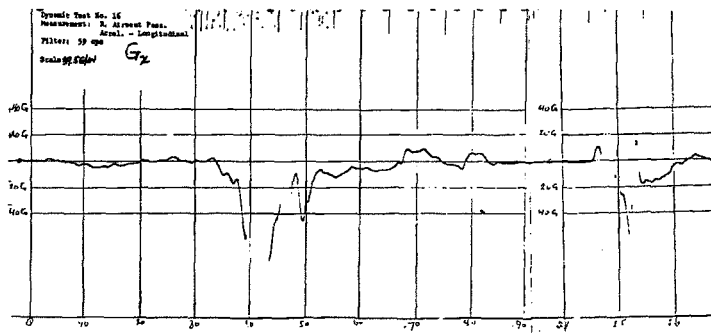
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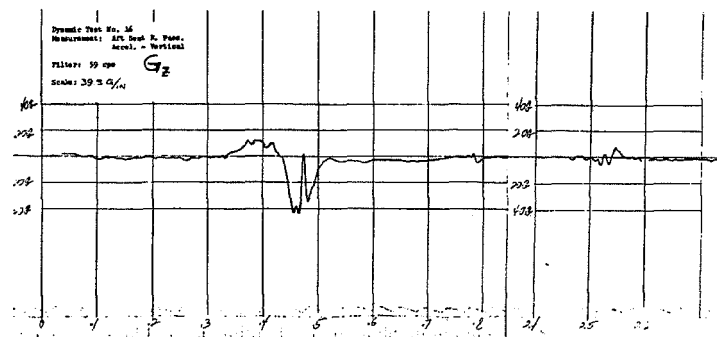
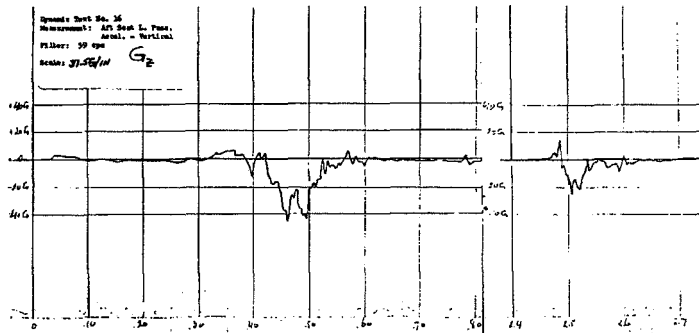
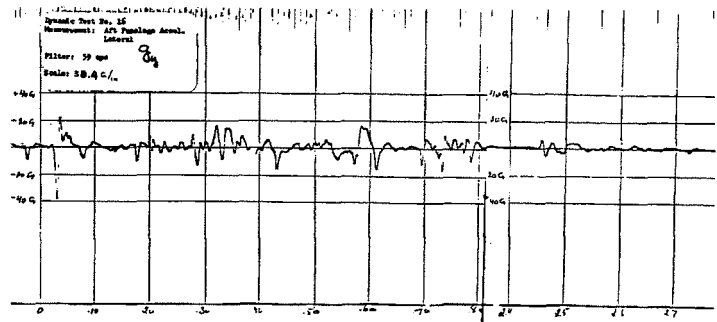
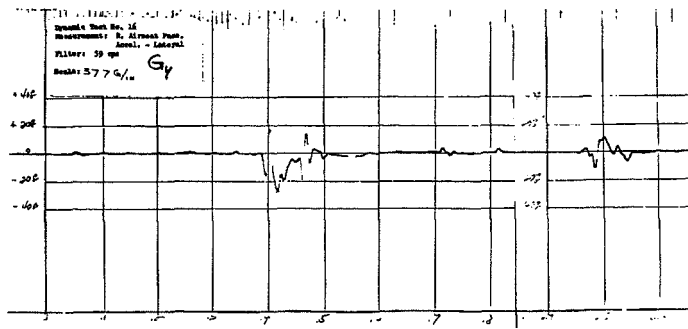
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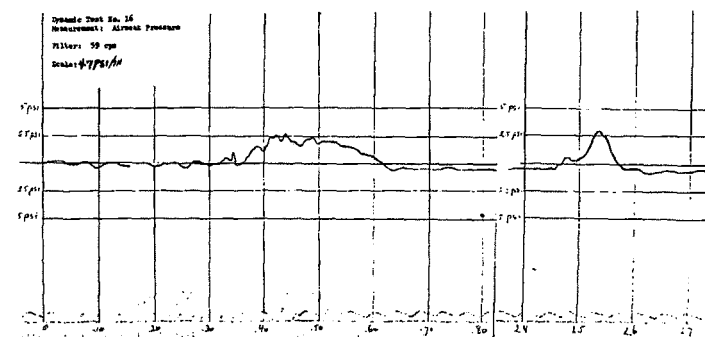
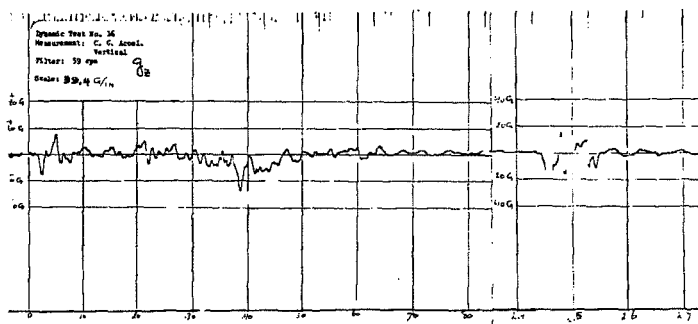
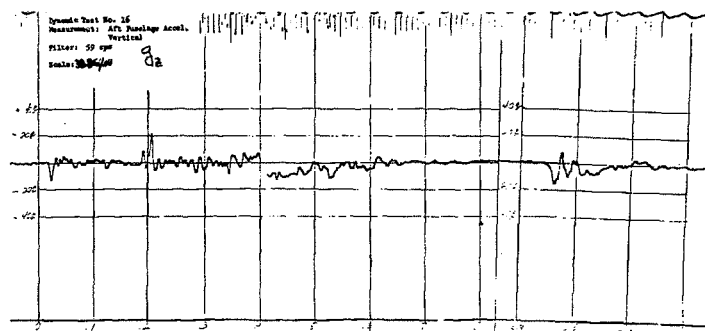
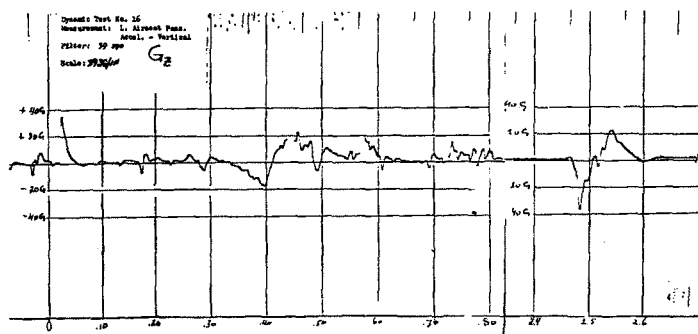
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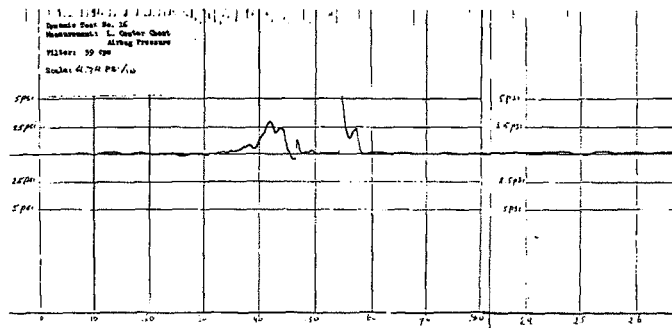
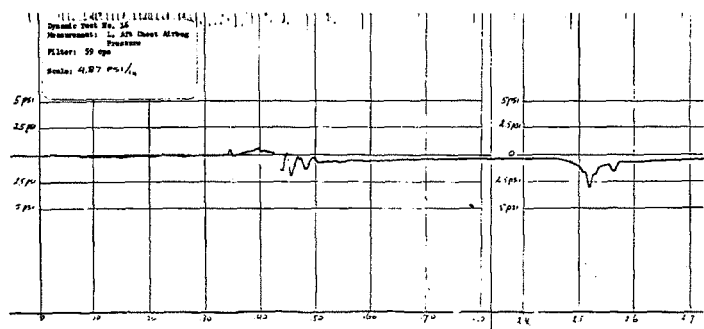
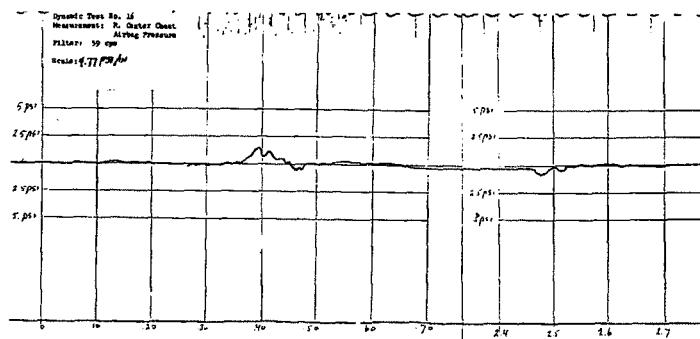
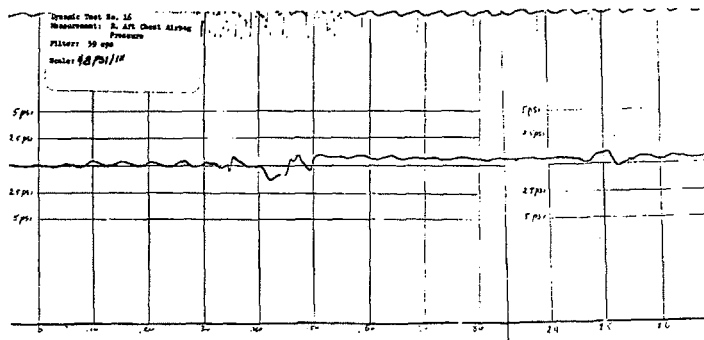
APPENDIX A--ACCELERATION DATA
C-45 CRASH TEST OF NOVEMBER 1964
(T-16 Dynamic Test)



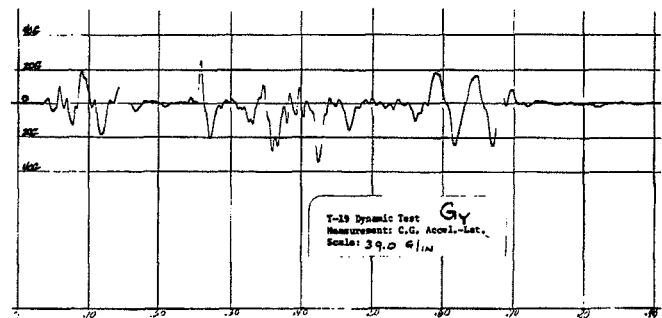
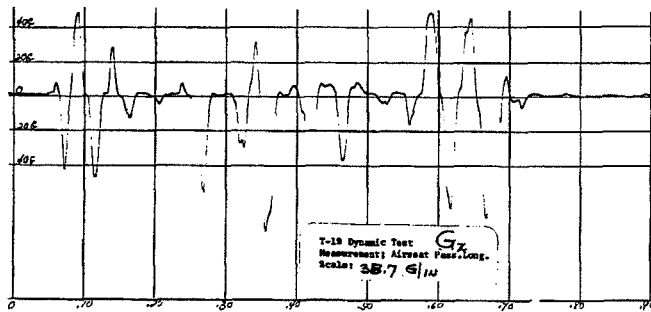
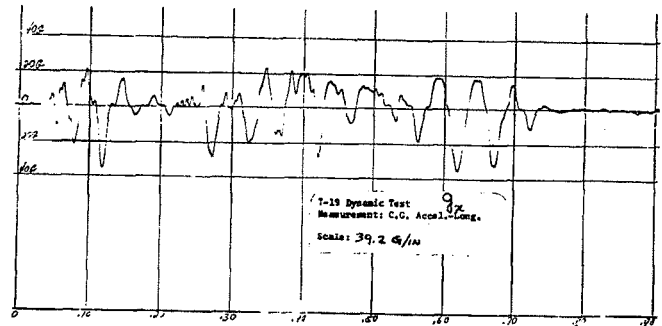
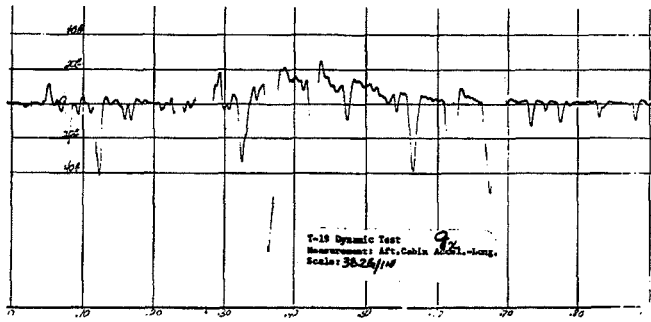


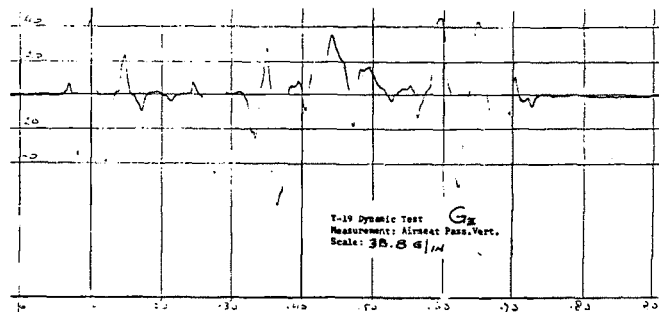
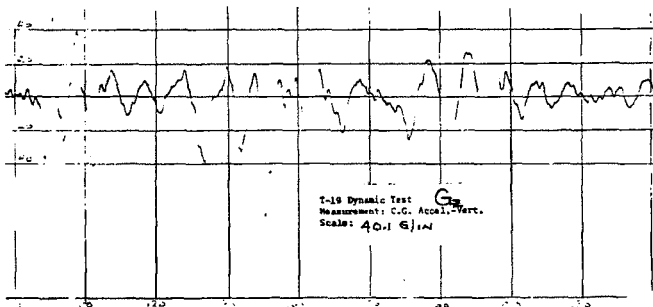
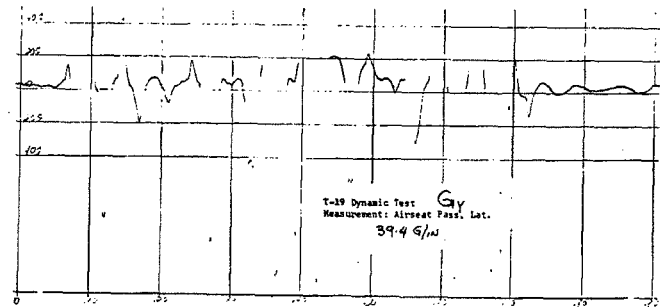
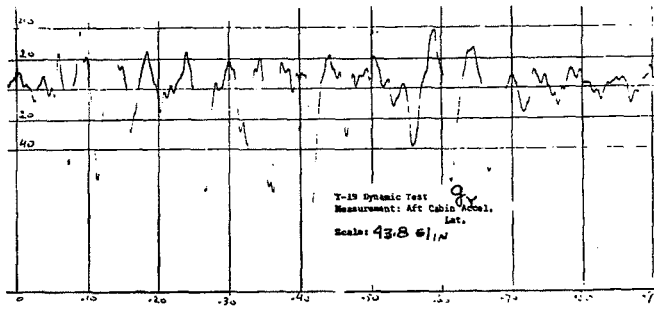


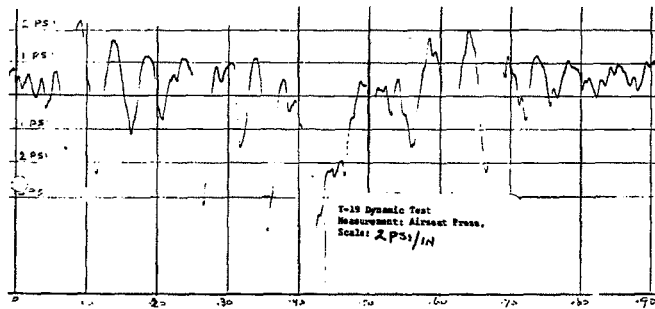
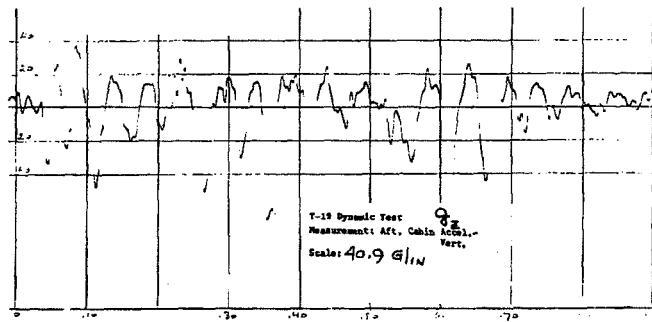




APPENDIX B--ACCELERATION DATA
C-45 CRASH TEST OF APRIL 1965
(T-19 Dynamic Test)







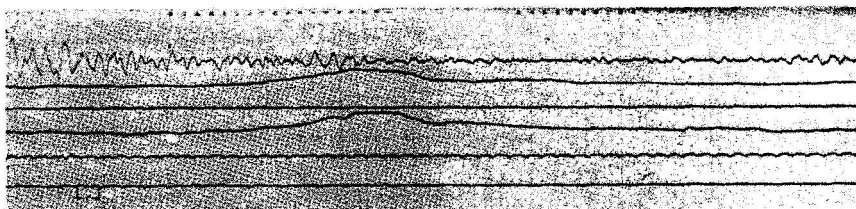
APPENDIX C--ACCELERATION DATA
FAA CATAPULT TRACK TEST
OF NOVEMBER 1965

(FAA DESIGNATION:
NASA SEAT TEST)

The oscillograph traces presented in this appendix have been reduced to facilitate presentation in this report. The full scale vertical height of the original traces was 7-in.

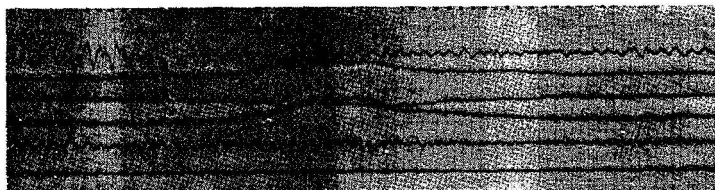
NASA SEAT TEST NO. 1
(Velocity 45.74 ft/sec)

2 Sled accel vert + dwn -----
5 Airseat dummy accel vert + fwd -----
6 Airseat dummy accel lat + left -----
7 Regular seat dummy accel vert + fwd -----
8 Regular dummy accel lat + right -----
Time & position -----



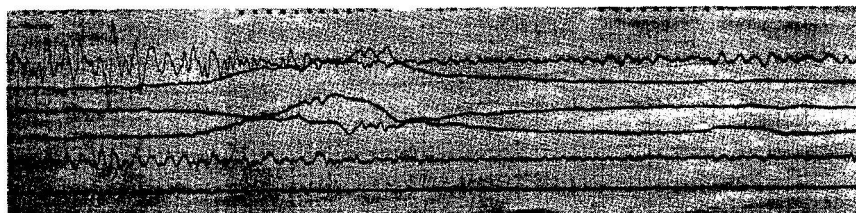
NASA SEAT TEST NO. 2
(Velocity 55.14 ft/sec)

2 Sled accel vert + dwn 15.5 g/in -----
5 Airseat dummy accel vert + dwn 13.0 g/in -----
6 Airseat dummy accel lat + left 11.3 g/in -----
7 Regular seat dummy accel vert + dwn 11.0 g/in -----
8 Sled accel lat + right 12.7 g/in -----
Time & position -----



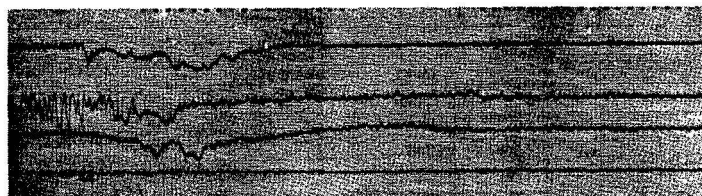
NASA SEAT TEST NO. 3
(Velocity 71.00 ft/sec)

2 Sled accel vert + dwn 15.3 g/in -----
5 Airseat dummy vert + dwn 12.9 g/in -----
6 Airseat dummy lat + left 10.9 g/in -----
7 Regular seat dummy vert + dwn 11.0 g/in -----
8 Sled accel lat + right 12.3 g/in -----
Time & position -----



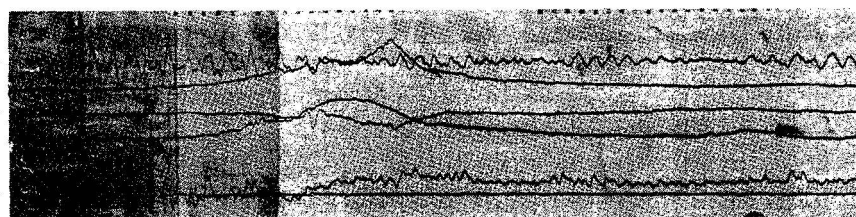
NASA SEAT TEST NO. 4
(Velocity 72.4 ft/sec)

1 Sled accel long. + fwd 14.4 g/in -----
3 Airseat dummy accel long. + fwd 22.8 g/in -----
4 Airseat dummy accel long. + fwd 12.1 g/in -----
Time & position -----



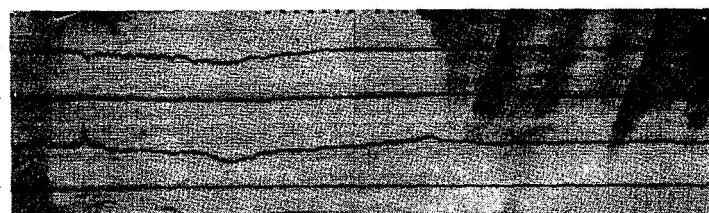
NASA SEAT TEST NO. 4
(Velocity 72.40 ft/sec)

2 Sled accel vert + dwn 15.3 g/in -----
5 Airseat dummy accel vert + dwn 13.1 g/in -----
6 Airseat dummy accel lat + left 11.3 g/in -----
7 Regular seat dummy accel vert + dwn 11.0 g/in -----
8 Sled accel lat + right 12.6 g/in -----
Time & position -----



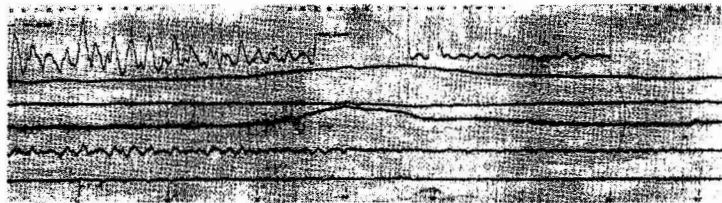
NASA SEAT TEST NO. 5
(Velocity 45.56 ft/sec)

1 Sled accel long. + fwd 14.8 g/in -----
3 Airseat dummy chest accel long. + fwd 22.8 g/in -----
4 Regular seat dummy chest accel long. + fwd 12.8 g/in -----
Sled time & position -----



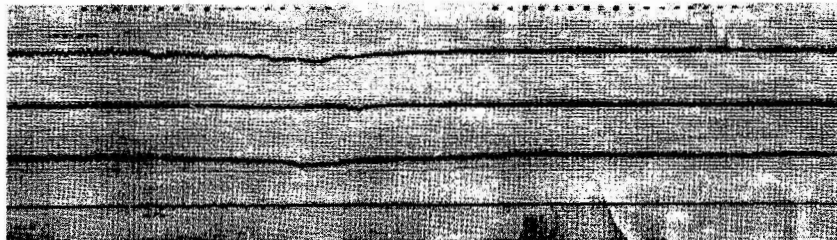
NASA SEAT TEST NO. 5
(Velocity 45.56 ft/sec)

2 Sled accel vert + dwn 15.8 g/in.-----
5 Airseat dummy accel vert + dwn 13.5 g/in.-----
6 Airseat dummy accel lat + left 11.4 g/in.-----
7 Regular seat dummy accel vert + dwn 11.1 g/in.-----
8 Sled accel lat + right 12.7 g/in.-----



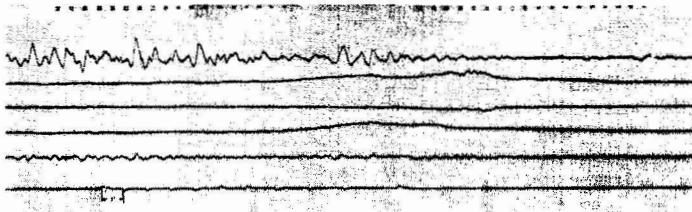
NASA SEAT TEST NO. 6
(Velocity 47.12 ft/sec)

1 Sled accel long. + fwd 23.5 g/in.-----
3 Airseat dummy accel long. + fwd 26.7 g/in.-----
4 Regular seat dummy accel long. + fwd 28.8 g/in.-----
Time & position -----



NASA SEAT TEST NO. 6
(Velocity 47.12 ft/sec)

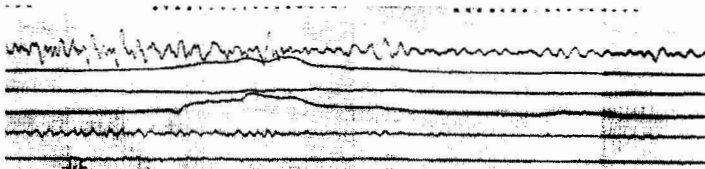
2 Sled accel vert + dwn 25.5 g/in.-----
5 Airseat dummy accel vert + dwn 25.9 g/in.-----
6 Airseat dummy accel lat + left 26.9 g/in.-----
7 Regular seat dummy vert + dwn 25.8 g/in.-----
8 Sled accel lat + right 27.7 g/in.-----
Time & position -----



NASA SEAT TEST NO. 7
(Velocity 53.99 ft/sec)

2 Sled accel vert + dwn *25.5 g/in.-----
5 Airseat dummy accel vert + dwn *25.9 g/in.-----
6 Airseat dummy accel lat + left--calibration questionable
7 Regular seat dummy accel vert + dwn *26.5 g/in.-----
8 Sled accel lat + right *27.7 g/in.-----
Time & position -----

*Calculated based on Tests 6, 9 & 10



NASA SEAT TEST NO. 7
(Velocity 53.99 ft/sec)

1 Sled accel long. + fwd 23.9 g/in.-----
3 Airseat dummy accel long. + fwd 26.7 g/in.-----
4 Regular seat dummy accel long. + fwd 28.5 g/in.-----
Time & position -----



NASA SEAT TEST NO. 8
(Velocity 43.03 ft/sec)

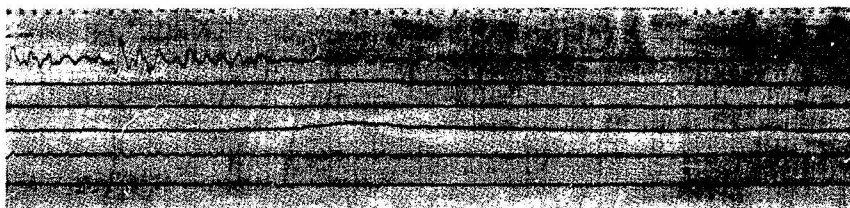
1 Sled accel long. + fwd 23.5 g/in.-----
3 Airseat dummy accel long. + fwd 26.7 g/in.-----
4 Regular seat dummy accel long. + fwd 28.2 g/in.-----



NASA SEAT TEST NO. 8
(Velocity 43.03 ft/sec)

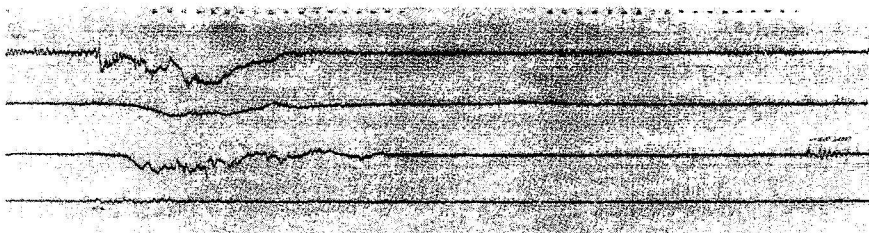
2 Sled accel vert + fwd 25.5 g/in. -----
5 Airseat dummy accel vert + dwn *25.9 g/in. -----
6 Airseat dummy accel lat + left --calibration questionable -----
7 Regular seat dummy accel vert + dwn *25.5 g/in. -----
8 Sled accel lat + right *27.7 g/in. -----
Time & position -----

*Calculated based on Tests 6, 9 & 10



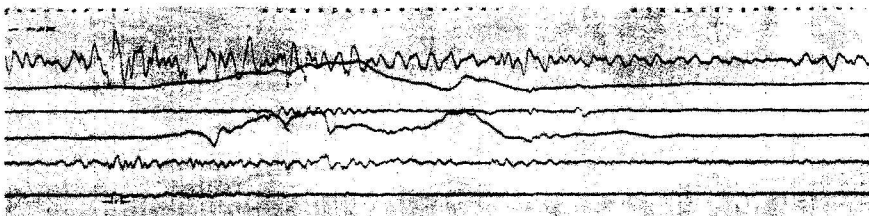
NASA SEAT TEST NO. 9
(Velocity 104.42 ft/sec)

1 Sled accel long. + fwd 23.5 g/in. -----
3 Airseat dummy accel long. + fwd 26.5 g/in. -----
4 Regular seat dummy accel long. + fwd 23.2 g/in. -----
Time & position -----



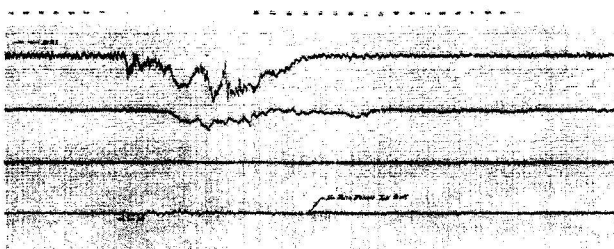
NASA SEAT TEST NO. 9
(Velocity 104.42 ft/sec)

2 Sled accel vert + dwn 25.5 g/in. -----
5 Airseat dummy accel vert * dwn 25.9 g/in. -----
6 Airseat dummy accel lat + left 33.1 g/in. -----
7 Regular seat dummy accel vert + dwn 26.5 g/in. -----
8 Sled accel lat + right 27.7 g/in. -----
Time & position -----



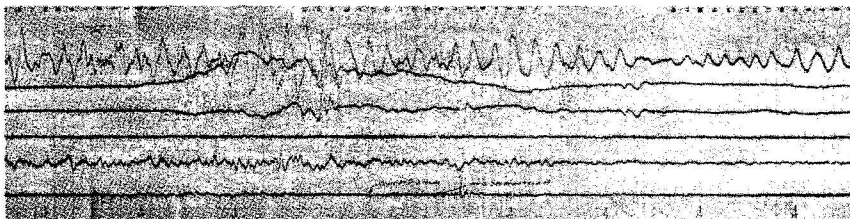
NASA SEAT TEST NO. 10
(Velocity 126.86 ft/sec)

1 Sled accel long. + fwd 24.4 g/in. -----
3 Airseat dummy accel long. + fwd 26.7 g/in. -----
4 Regular seat dummy accel long. --dummy removed -----



NASA SEAT TEST NO. 10
(Velocity 126.86 ft/sec)

2 Sled accel vert + dwn 26.1 g/in. -----
5 Airseat dummy accel vert + dwn 25.9 g/in. -----
6 Airseat dummy accel lat + left 32.1 g/in. -----
7 Regular seat dummy accel --dummy removed -----
8 Sled accel lat + right 27 g/in. -----



APPENDIX D

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Bertrand, 2,834,606, May 13, 1958, Safety Device for Passengers

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2,649,311

SAFETY CUSHION ASSEMBLY FOR
AUTOMOTIVE VEHICLES

John W. Hetrick, Newport, Pa.

Application August 5, 1952, Serial No. 302,830

5 Claims. (Cl. 280-150)

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This invention relates to safety devices for automotive vehicles, and more particularly, has reference to an inflatable cushion assembly adapted to be mounted in the passenger compartment of a vehicle, and arranged to be inflated responsive to sudden slowing of the forward motion of the vehicle.

It is well appreciated that many persons suffer death or serious injury when hurled against an unyielding structural portion of an automotive vehicle, when the vehicle is involved in a collision or is braked suddenly and heavily to avoid a collision.

My main object, in devising an inflatable cushion assembly for automotive vehicles, is to provide a means whereby death or injury can be prevented, when a situation such as that described above occurs.

To this end, the inflatable cushion assembly which I have devised includes one or more cushions which are normally deflated so as to occupy a minimum space within the passenger compartment of the vehicle. The cushions are adapted to be inflated from an air accumulator or reservoir, which is mounted in the vehicle in the engine compartment or at some other location. A valve is interposed between the inflatable cushion or cushions and the air accumulator, and is normally closed, so as to keep the cushions normally deflated. However, means is associated with the valve which acts responsively to a sudden slowing of the forward motion of the vehicle, such as that occurring when the vehicle is involved in a collision or is braked heavily. This means is adapted to cause the valve to be immediately opened under conditions such as those described, thus to cause an instantaneous inflation of the cushion or cushions, to cause said cushions to define yielding surfaces against which a passenger may be thrust without incurring serious injury.

An important object of the present invention, in this connection, is to provide an inflatable cushion assembly of the type stated which will be so designed as to cause said cushions to be normally disposed out of the way, so that they will not interfere with normal operation of the vehicle or movement of the passengers within the vehicle.

Another object of importance is to provide an assembly of the type stated wherein the cushions can be provided in any number or shape, thus to permit one cushion, for example, to be mounted upon the steering wheel of the vehicle, another cushion to be mounted upon the glove compart-

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ment of the vehicle, and a third cushion to be mounted upon the instrument panel of the vehicle. The construction, in this regard, permits additional cushions to be added wherever desired, as for example, along the back of the front seat.

Another object of importance is to provide a device of the type stated which can be mounted upon a vehicle as a separate accessory or attachment, without involving the modification or redesigning of any important structural parts of said vehicle.

Still another object of importance is to provide a device as stated which can be reset in a normally inoperative position from the interior of the passenger compartment, with maximum speed and ease.

Still another object is to provide a device of the type stated which, when manufactured in one form, can be used in any of various makes of vehicles, and can be mounted upon the vehicle with little difficulty.

A further object is to provide a safety cushion assembly which can be manufactured at low cost and from relatively inexpensive, readily available materials.

Other objects will appear from the following description, the claims appended thereto, and from the annexed drawing, in which like reference characters designate like parts throughout the several views, and wherein:

Figure 1 is a longitudinal sectional view through a safety cushion assembly formed in accordance with the invention, some parts being broken away, other parts being shown in side elevation, and still other parts being illustrated somewhat diagrammatically;

Figure 2 is a diagrammatic view showing the relationship of the several parts to structural parts of the vehicle disposed within the passenger compartment, said vehicle being illustrated fragmentarily; and

Figure 3 is a sectional view taken diametrically through one of the cushions, said cushion being adapted for mounting upon the steering wheel of the vehicle.

Referring to the drawings in detail, the reference numeral 10 has been applied to a cylinder, said cylinder being adapted for mounting upon a selected structural member, not shown, of an automotive vehicle. The cylinder, for example, can be mounted within the engine compartment of the vehicle, so as to be disposed in an out-of-the-way location.

The cylinder 10 is formed with a longitudinal bore 12 closed at one end by an end wall 14, said

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end wall merging into a thickened side wall portion 16 extending from end to end of the cylinder at the underside thereof.

The cylinder 10 can be mounted upon a suitable bracket 17, which bracket would be connected fixedly to said structural part of the vehicle.

At its other end, the bore 12 is closed by a removable cap 18, said cap being connected to the side wall of the cylinder by screws 20 or equivalent fastening means.

Mounted within the bore 12, to shift longitudinally thereof, is a rollable weight 22, said weight being provided with rollers 24 contacting the side wall of the bore 12, thus to permit free movement of the weight 22 from end to end of the bore.

In that end of the weight 22 disposed adjacent the end wall 14 of the cylinder, there is formed a recess 26 receiving one end of a spring 28, the other end of which is engaged against a flanged plate 30 spaced selected distances from the end wall 14 by a tension-adjusting screw 32. The tension-adjusting screw 32 is threadable in the end wall 14, and is retained in selected positions of adjustment by means of a lock nut 34.

Formed in the thickened side wall portion 16 of the cylinder 10 is a transversely extended opening 36, said opening communicating at one end with the bore 12, and communicating at its other end with a counterbore 38. A threaded plug 40 is engaged in the counterbore, the counterbore having complementary threads, and carried slidably within the opening 36 is a detent 42, urged inwardly of the bore 12 by means of a spring 44. The spring 44 is circumposed about a stem secured to the detent, said stem being integrally formed as the inner end of an elongated, flexible cable 46 slidably mounted within a cable housing 48. At its outer end, the cable 46 has a knob 50 which, as shown in Figure 2, can be mounted upon the instrument panel of a vehicle V.

It will thus be seen that if the knob 50 is pulled, the detent 42 will be retracted within the opening 36, against the action of the spring 44.

The weight 22 has a recess 51 formed in its side wall, and if the weight 22 is shifted toward the right in Figure 1, the detent 42 will be cammed downwardly by the weight, and will then be urged into the recess 51 by the spring 44. Thus, the weight 22, when shifted to the right in Figure 1, will be releasably held in the position to which it is shifted by the detent. When, however, it is desired that the weight be returned to its normal position shown in Figure 1, the knob 50 is pulled, as a result of which the detent 42 is disengaged from the recess 51. The spring 28 will then urge the weight 22 to the left in Figure 1.

Formed in the cap 18 is a relatively large opening 52, and extending through said opening is a connecting rod 54, said connecting rod being fixedly attached at one end to the weight 22. The connecting rod 54 extends through a rod housing 56, and circumposed about one end of said housing is the smaller end of a flexible, cup-like boot 58 of soft rubber or similar material. The larger end of the boot 58 is engaged about the adjacent end of the cylinder 10.

At its other end, the cable housing 56 is attached to a boss 60 formed upon a plate 62 spaced away from the valve block by a gasket 64, fastening elements 66 being extended through the plate 62 and gasket 64 for attaching the same to

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the valve block. The valve block has been designated by the reference numeral 68 and is of relatively elongated formation, said block having an end to end, longitudinal bore 70.

Slidably mounted in the bore 70 is a valve member 72, said valve member being formed as an elongated cylindrical piston connected at one end to the rod 54. It will thus be seen that when the weight 22 is shifted to the right in Figure 1, it will carry with it the valve member 72.

Circumposed about the valve member 72, and spaced longitudinally of the valve member, are annular sealing rings 74, said rings having wiping engagement with the wall of the bore 70. The sealing rings 74 are disposed at opposite sides of a passage 76 communicating with the bore 70, when the valve member is in the normal, closed position thereof shown in Figure 1. The passage 76 is counterbored and threaded for a part of its length, for engagement therein of one end of a conduit portion 78, said conduit portion extending from an air accumulator 80 adapted to be charged with a supply of air pressure through a conventional valve 82.

Integral with the valve member 72 is a reduced extension 84, said extension merging into an outer end portion 86. The end portion 86 normally projects beyond one end of the valve block 68, as shown in Figure 1, and is provided with an annular sealing gasket 88.

At its outer, projecting end, the end portion 86 is flanged as at 90, and engaged over said flange is the smaller end of a flexible, rubber boot 92, the larger end of which is fitted about the adjacent end of the valve block 68.

Also formed in the valve block 68 is an outlet passage 94, offset longitudinally of the block from the passage 76. The outlet passage 94 is counterbored and threaded, to receive a fitting provided at the inlet end of a second conduit portion 96. The conduit portion 96 is provided, intermediate its ends, with a relief valve designated generally by the reference numeral 98.

Considering the construction of the relief or safety valve 98, it will be noted from Figure 1 that said valve is provided with a tubular body 100 integral, intermediate its ends, with a lateral projection 102. An inlet opening 104 is formed in the projection 102, communicating with the bore of the body 100.

A valve disc 106 is generally disposed in a position to close the opening 104, being urged against one end of the opening by a spring 108. The spring 108 is arranged for adjustment of the tension thereof, by a tension-adjusting screw 110 threaded in the outer end of the projection 102, and held in selected positions to which it is threaded by a lock nut 112.

Relief ports 114 are formed in the projection 102, intermediate the opposite ends of said projection, a pair of said relief ports being provided in the present instance, with the ports of said pair being diametrically opposite one another.

The purpose of the relief or safety valve 98 is to prevent rupture of the conduit extending from the accumulator to the safety cushion or cushions of the device, in the event the accumulator is charged with an excessive amount of air. When pressure within the conduit exceeds a predetermined amount, the relief valve will open against the action of the spring 108.

Also provided in the conduit between the air accumulator and the several protective cushions is a main valve 116, said main valve being of the manually operable type and being adapted to

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permit the entire device to be disposed in an inoperative position, whenever desired.

A reset cable 116 is provided, for resetting the control valve 72 whenever desired, said reset cable being connected to the end portion 86 and being extended through a housing 120. The reset cable 116 is provided with a knob adapted to be mounted upon the instrument panel of the vehicle, in close proximity to the knob 80. Should the device be accidentally tripped, causing inflation of the cushions, the reset knobs provided on cables 46, 116 can be pulled to return the parts to their normally inoperative position. Additionally, these knobs are pulled whenever the device has gone into operation under emergency conditions, and is to be reset for further use.

I provide, on the conduit extending from the air accumulator to the safety cushions, a plurality of branches, the number of said branches depending upon the number of cushions to be inflated. One branch has been designated by the reference numeral 122, and as shown in Figure 2, extends from the air conduit to an inflatable, generally circular cushion 124 (Figures 2 and 3).

The cushion 124 has at its inner end an end wall 126 secured to the base of a cup-like receptacle 128, said receptacle having a peripheral flange 130 circumposed about the inner end portion of the cushion 124. Provided upon the base of the receptacle 128 are spaced clips 132, adapted to engage the conventional horn ring of the vehicle steering wheel.

It will thus be seen that the cushion 124 will be normally deflated, but when inflated under emergency conditions, will extend outwardly from the steering wheel toward the operator of the vehicle, to cushion the force with which said operator is thrown against the steering wheel in a collision.

I also provide a second branch 134, extending to an elongated, tapered safety cushion 136 mounted upon the instrument panel of the vehicle, to protect one seated next to the vehicle operator. A third branch 138 extends to a rectangular cushion 140 mounted upon the glove compartment door of the vehicle.

It will be readily appreciated that any number of branches can be provided upon the conduit, with said branches leading to cushions located at desired places within the vehicle, and formed to appropriate shapes.

When a collision occurs, or when it is necessary to brake the vehicle suddenly, the weight 22 will tend to continue its forward motion, despite the fact that the forward motion of the vehicle has been stopped or greatly slowed. As a result, the weight 22 will shift to the right in Figure 1, against the action of the spring 28, and this will cause the valve member 72 to move out of its normal position, in which normal position it closes the passage 76. When the valve member is moved from its normal position, the reduced portion 84 will be disposed above the passage 76, and will permit the free movement of air from the air accumulator 80 to one or more safety cushions provided in the device.

When the weight 22 has been shifted to the right in Figure 1, it will be held in the position to which it is shifted by the detent 42, until such time as the device is to be reset for further use. At that time, the knobs provided on cables 46, 116 are pulled and the valve member and weight 22 will be returned to their proper locations

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within the valve block and cylinder 10, respectively.

It will also be understood that the air accumulator 80 will be normally charged with a suitable quantity of air under pressure, and it is obvious that the air accumulator can be readily filled from the ordinary air pumps provided in a service station.

It is believed apparent that the invention is not necessarily confined to the specific use or uses thereof described above, since it may be utilized for any purpose to which it may be suited. Nor is the invention to be necessarily limited to the specific construction illustrated and described, since such construction is only intended to be illustrative of the principles of operation and the means presently devised to carry out said principles, it being considered that the invention comprehends any minor change in construction that may be permitted within the scope of the appended claims.

What is claimed is:

1. A safety cushion assembly for automotive vehicles comprising: normally stationary means arranged to shift in position responsive to a predetermined deceleration of a vehicle; a normally closed valve connected to said means to move to open position on shifting of said means; an air accumulator; at least one inflatable cushion adapted for mounting within a vehicle; and a conduit extending between said accumulator and cushion and normally closed by the valve, for passage of air from the accumulator to the cushion for inflating the same responsive to opening of the valve.

2. A safety cushion assembly for automotive vehicles comprising: a cylinder adapted to be mounted upon a vehicle; a weight within the cylinder and shiftable longitudinally thereof responsive to deceleration of said vehicle; a normally closed valve connected to said weight to move to open position on shifting of said weight; an air accumulator; at least one inflatable cushion adapted for mounting within said vehicle; and a conduit extending between said accumulator and cushion and normally closed by the valve, for passage of air from the accumulator to the cushion for inflating the same responsive to opening of the valve.

3. A safety cushion assembly for automotive vehicles comprising: a cylinder adapted to be fixedly mounted on a vehicle; a weight within the cylinder and shiftable longitudinally thereof in one direction responsive to sudden slowing of the forward motion of said vehicle; yielding means interposed between the weight and one end of the cylinder and arranged to normally urge the weight in an opposite direction; a normally closed valve connected to said weight to move to open position on shifting of the weight in said one direction; an air accumulator; at least one inflatable cushion adapted for mounting within said vehicle in the passenger compartment thereof; and a conduit extending between said accumulator and cushion and normally closed by the valve, for passage of air from the accumulator to the cushion for inflating the same responsive to opening of the valve.

4. A safety cushion assembly for automotive vehicles comprising: a cylinder adapted to be fixedly mounted on a vehicle; a weight mounted within the cylinder to shift longitudinally thereof in one direction responsive to sudden slowing of the forward motion of said vehicle; yielding means interposed between the weight and one

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end of the cylinder and arranged to normally urge the weight in an opposite direction; a manually releasable latch in the cylinder adapted to engage the weight after movement thereof in said one direction; a normally closed valve connected to said weight to move to an open position on shifting of the weight in said one direction; an air accumulator; at least one inflatable cushion adapted for mounting within said vehicle in the passenger compartment thereof; and a conduit extending between said accumulator and cushion and normally closed by the valve, for passage of air from the accumulator to the cushion to inflate the same responsive to opening of the valve.

8. A safety cushion assembly for automotive vehicles comprising: a cylinder adapted to be fixedly mounted on a vehicle; a weight mounted within the cylinder to shift longitudinally thereof in one direction responsive to sudden slowing of the forward motion of said vehicle; yielding means interposed between the weight and one end of the cylinder and arranged to normally urge the weight in an opposite direction; a manually releasable latch in the cylinder adapted to engage a weight after movement thereof in said one direction; a valve block adapted to be mounted in said vehicle adjacent the cylinder and having a longitudinal bore; a valve member

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connected to said weight and mounted in the bore of the valve block to shift longitudinally thereof in one direction on shifting of the weight in said one direction, said block having a passage communicating with said bore and normally closed by the valve, said valve being arranged to open said passage on shifting of the valve in said one direction within its associated bore; an air accumulator; at least one inflatable cushion adapted for mounting within said vehicle in the passenger compartment thereof; and a conduit extending between said accumulator and cushion and including said passage, said conduit being normally closed by the valve and being adapted when opened to permit passage of air from the accumulator to the cushion for inflating the cushion responsive to opening of the valve.

JOHN W. HETRICK.

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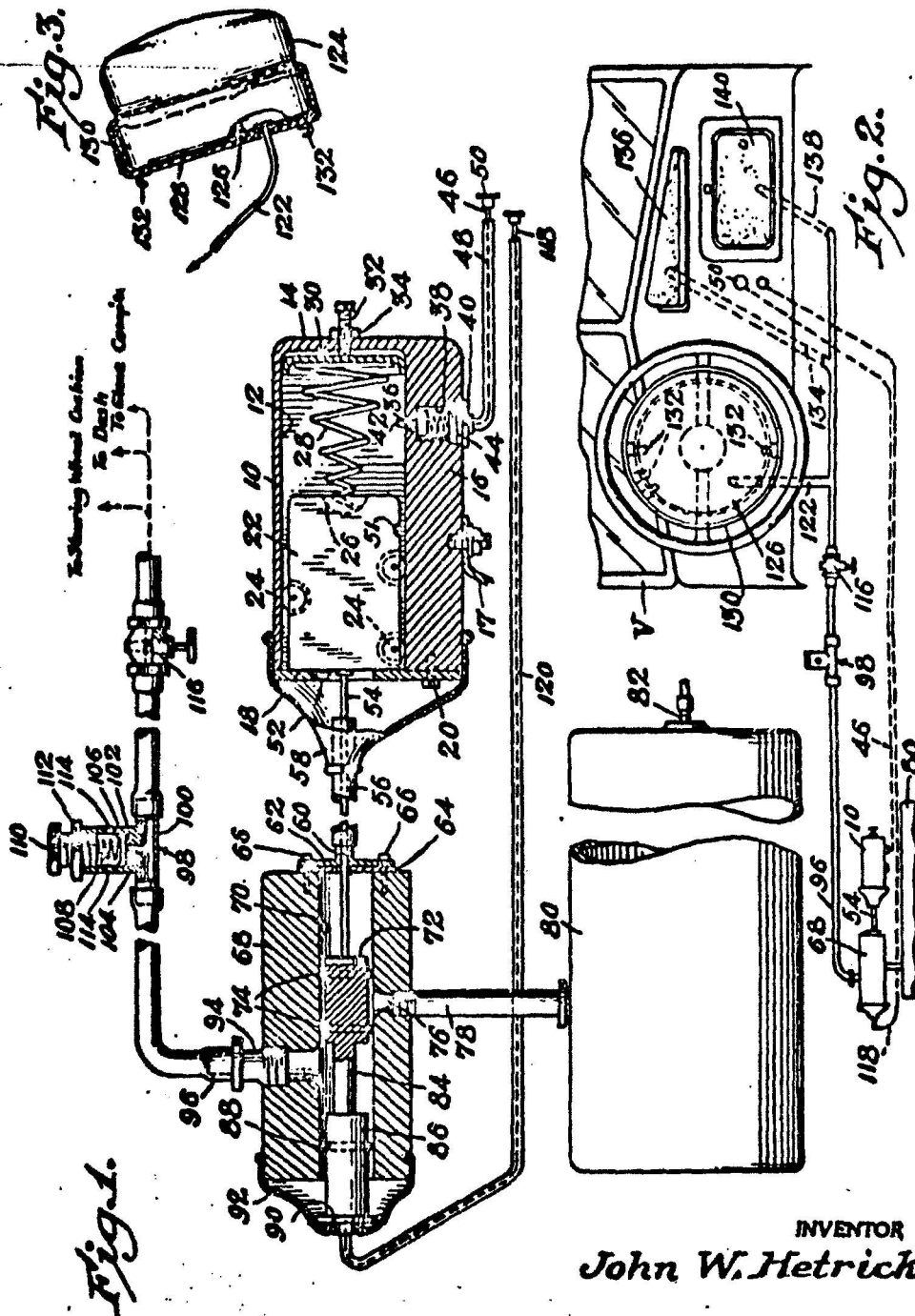
Aug. 18, 1953

J. W. METRICK

2,649,311

SAFETY CUSHION ASSEMBLY FOR AUTOMOTIVE VEHICLES

Filed Aug. 8, 1952



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1

2,834,606

SAFETY DEVICE FOR PASSENGERS

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Application October 5, 1955, Serial No. 538,748

3 Claims. (Cl. 280—150)

The present invention relates to safety devices used in passenger conveyances for protecting passengers against being thrown in direct contact with non-yieldable parts of the conveyance should said conveyance become involved in an accident.

Another object of the invention is to provide, at a location within a conveyance, a safety device having a normally compact deflated bag which can be immediately inflated when it is observed that an unavoidable crash is imminent, and for providing with said bag a cushion-like barrier between a passenger and parts of the conveyance which could do bodily harm to the passenger should he be thrown thereagainst.

Another object of the invention is to provide, in a safety device as outlined above, an inflatable bag positioned relative to a seated passenger in a conveyance and structure of the conveyance whereby said bag will be relocated to a position between and in engagement with both the structure of the conveyance and the passenger upon its inflation and thereby support the passenger against movement from a seated position when a crash occurs.

Another object of the invention is to provide, in a device as set forth, a plurality of deflated bags which are at locations within a conveyance where they are least noticeable and are arranged relative to one another for immediate inflation and for substantially encasing the passengers of the conveyance, either singularly or in numbers, should a crash occur.

A further object of the invention is to provide, in a safety shock-absorbing device of the above character, a novel construction and arrangement of parts for effecting immediate inflation of a deflatable folded bag.

A still further object of the invention is the provision of a safety shock-absorbing device of the character set forth wherein a time delay element automatically deflates the shock-absorbing bag after a designated period of time has elapsed since its inflation.

It is also an object of the invention to provide a safety shock-absorbing device of the above-indicated character, which is simple and substantial in construction, economical to manufacture, and thoroughly efficient and practical in use.

These, together with various auxiliary features and objects of the invention which will later become apparent as the following description proceeds, are attained by the present invention, a preferred embodiment of which has been illustrated by way of example only in the accompanying drawings, wherein:

Figure 1 is a longitudinal, vertical, sectional view through an automobile body with passengers therein and showing a plurality of the improved safety devices in deflated positions and at various selected locations in said body;

Figure 2 is a similar sectional view showing the safety devices inflated and supporting passengers in their normal seated positions;

Figure 3 is a fragmentary cross sectional view of the

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automobile body, showing in full lines safety devices deflated, and in dotted lines, a position of a bag when inflated;

Figure 4 is an end view of one of the safety devices in deflated, folded position and ready for use;

Figure 5 is a longitudinal section and elevation taken substantially on line 5—5 of Figure 4, and with the central portion thereof broken away;

Figure 6 is a cross sectional view taken on line 6—6 of Figure 5;

Figure 7 is a view similar to Figure 6 but showing parts in inflating position;

Figure 8 is a fragmentary sectional view similar to one end portion of Figure 5, but showing parts in inflating position; and,

Figure 9 is a wiring diagram showing electric controls for inflating and deflating the bags of the safety devices.

Referring now more specifically to the accompanying drawings wherein like numerals designate similar parts throughout the various views, the numeral 10 indicates a passenger-carrying compartment of a conveyance, which in the present instance, is the body of an automobile, having both a forward seat 11 and rear seat 12 therein. The automobile body is of the usual closed type with a permanent top 13, side and rear windows 14 and 15, respectively, and windshield 16 extending upwardly and in advance of an instrument panel 17.

The improved safety devices forming the subject matter of this invention and generally indicated by the numeral 20 may vary in number, and their locations relative to one another and relative to differently shaped and constructed compartments of conveyances may be altered from that shown in the drawings. For the purpose of illustration, four safety devices, A, B, C, and D, are shown as being mounted in pairs and parallel to one another on the underside of the top 13 of the automobile passenger compartment and as extending transversely thereof; two safety devices, E, and F, as also being mounted on the underside of the top 13 but end to end and extending longitudinally above each pair of side windows 14; one transversely extending safety device, G, as being mounted on the rear of the back of the forward seat 11; and one transversely extending safety device H as being mounted along the lower portion of the instrument panel 17.

Each safety device 20 is provided with an elongated casing 21 that has a compressed air chamber 22 therein and a cylindrical valve-receiving chamber 23 extending longitudinally therethrough and at a lower corner of a flat longitudinal side 24 of said casing. A movable valve element 25 in the form of a round rod is closely fitted and rotatably supported in the cylindrical chamber 23 and has a plurality of spaced L-shaped openings 26 therethrough that are adapted to align with either of two sets of oppositely arranged openings 27 and 28 in the wall of said cylindrical chamber leading to the compressed air chamber 22 and to the outside of the casing 21, respectively, upon a quarter turn of the rotary valve element. When either end of each L-shaped opening 26 is in alignment with either an opening 27 or 28, the other end of said L-shaped opening 26 is registered with one of another set of openings 29 through outwardly flanged nipples 30.

Slipped over the flanged nipples 30 and held in place by retainer rings 31 are the open ends of separate and spaced sleeve extensions 32 of a relatively large airtight bag 33. The bag is of substantially the same width as the length of the casing 21 to which it is attached, and when not in use, is folded and held against the flat side 24 of the casing by the free ends of oppositely disposed pairs of spring clips 34 secured to the casing, as best shown

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In Figures 4, 5, and 6. These clips are constructed to immediately release the bag upon the start of inflation of said bag.

On reduced extensions at the opposite ends of the rotary element 25 of the valve and outwardly of the ends of the casing 21 are fixed crank arms 35 and 36. A spring 37 has one end thereof connected to the crank arm 35 and has its other end connected to the casing, as at 38, for yieldably holding the valve 25 in a position registering its L-shaped openings 26 with the openings 28 leading to the atmosphere and openings 29 leading to the bag 33. The other crank arm 36 is connected by a pair of links 39 to the actuated element 40 of a solenoid 41 mounted on an end wall of the casing 21. Upon energizing the solenoid 41, the rotary element 25 of the valve is rotated one quarter of a turn against tension of the spring 37 and registers the L-shaped openings therein with the openings 27 and 29 communicating the interior of the bag 33 with the compressed air chamber 22. The purpose of having a number of openings 26 in the valve 25 that communicates the compressed air chamber 22 with the interior of the bag 33 and the interior of the bag with the atmosphere is to inflate and deflate the bag evenly and as rapidly as possible.

There is a small opening 42 in the wall of the casing 21 to the compressed air chamber 22, and a valve extension 43 of the type used on pneumatic tires is fixed at said opening through which air under pressure is supplied to the chamber.

Mounted on the instrument panel 17 within quick and convenient reach of the operator of the automobile is a time delay switch 44 which, when manually operated, immediately closes an electric circuit through wires 45 and 46 and a battery 47 to the solenoids 41 of all safety devices 20, and which, after a predetermined time has elapsed, breaks the electric circuit. In the wiring diagram shown in Figure 9, it will be noted that the circuit is bridged between a pair of spring fingers 48 by a movable contact 49 on a manually operated plunger 50 of the switch, and at the same time, a small spring 51 in an air-metering chamber 52 is compressed for time control of return movement of the movable contact 49 to break the circuit.

During normal operation of the conveyance, which in the present instance is shown as an automobile, all air bags 33 remain neatly folded and at locations where they do not interfere with the vision or comfort of the passengers, as best shown in Figure 1 of the drawings. When it is apparent that an unavoidable crash of the automobile is about to occur, the operator of the vehicle presses the plunger 50 of the switch 44 which immediately causes an inflation of all bags 33. The expanding of the bags, as shown in Figure 2, extends portions of said bags throughout the major portions of the spaces between the passengers and structural parts of the interior of the passenger compartment of the automobile, thus applying pressure on the passengers for supporting them in their normal seated positions when the crash occurs. After sufficient time has elapsed since the crash to render the air bags no longer useful, said bags are automatically deflated by the exhausting of air in the bags to the atmosphere.

While a number of bags are shown at positions for completely surrounding the passengers of a crashing automobile, it is to be understood that certain of the safety devices may be dispensed with and the devices used only as barriers between the passengers and structural parts against which passengers are more often thrown during automobile accidents.

In view of the above description, taken in conjunction with the accompanying drawings, it is believed that a clear understanding of the construction, operation, and advantages of the improved invention will be quite apparent to those skilled in this art. A more detailed description is accordingly deemed unnecessary.

It is to be understood, however, that even though there

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is herein shown and described a preferred embodiment of the invention, various changes may be made without departing from the spirit and full intendment of the invention.

What is claimed is:

1. A safety device for use in a passenger-carrying compartment of a conveyance, said safety device comprising a casing having therein a compressed fluid chamber, an inflatable bag connected to said casing, supporting means for yieldably holding said bag when deflated in a folded position adjacent said casing, a valve for communicating the chamber of said casing with the interior of said bag and for communicating the interior of the bag with the atmosphere, spring means for normally and yieldably holding said valve in a position communicating the interior of the bag with the atmosphere, an electric solenoid connected to said valve and when energized moves said valve to the position where the chamber of the casing and interior of the bag communicate, said bag being forced from its yieldable support and extended by the expansion thereof to a position between a passenger and structural parts of the conveyance upon the inflation thereof, and a time delay electric switch conveniently arranged in said compartment of the conveyance and wired to said solenoid for energizing the same to inflate the bag and for de-energizing said solenoid to deflate the bag after a period of time has elapsed since said inflation.

2. A safety device for use in a passenger-carrying compartment of a conveyance, said safety device comprising a casing having a chamber therein containing a fluid under pressure, an inflatable bag connected to said casing, supporting means for yieldably holding said bag when deflated in a folded position adjacent said casing, a valve for communicating the chamber with the interior of the bag and for communicating the interior of the bag with the atmosphere, spring means for normally and yieldably holding said valve in a position communicating the interior of the bag with the atmosphere, operating means connected to said valve so as to move and hold said valve to the position where the interiors of the chamber and bag communicate, said bag being forced from its yieldable supporting means and extended by the expansion thereof to a position between a passenger and structural parts of the conveyance upon the inflation thereof, and a time delay mechanism set by said operating means that allows said spring means to return said valve to its initial position for deflating the bag after a period of time has elapsed since said inflation.

3. A passenger-cushioning and -supporting apparatus in combination with a passenger-carrying compartment of a conveyance, said passenger-cushioning and -supporting apparatus comprising a plurality of deflated and collapsible bags supported within said compartment at different locations where they are inconspicuous and are out of the way, an inflating means for each of said bags that is constructed and arranged relative to its associated bag so as to immediately inflate the bag when it is apparent that a crash of the conveyance is imminent, said bags being of sizes and an arrangement relative to one another that when inflated are extended by the expansion thereof into contact with one another and into spaces between the passengers and interior surfaces of said compartment, deflating means for each of said bags, and a time delay element that operates all of said deflating means after a period of time has elapsed since the inflation of said bags.

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May 13, 1958

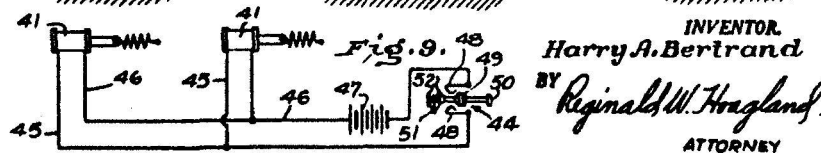
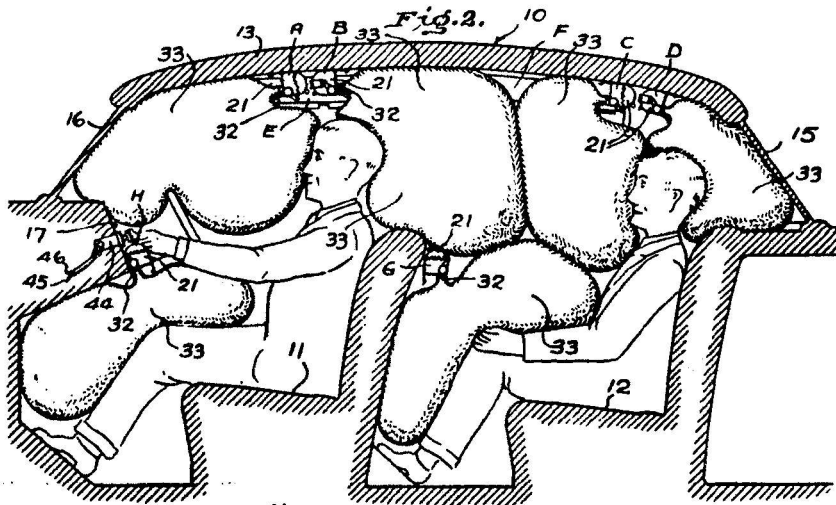
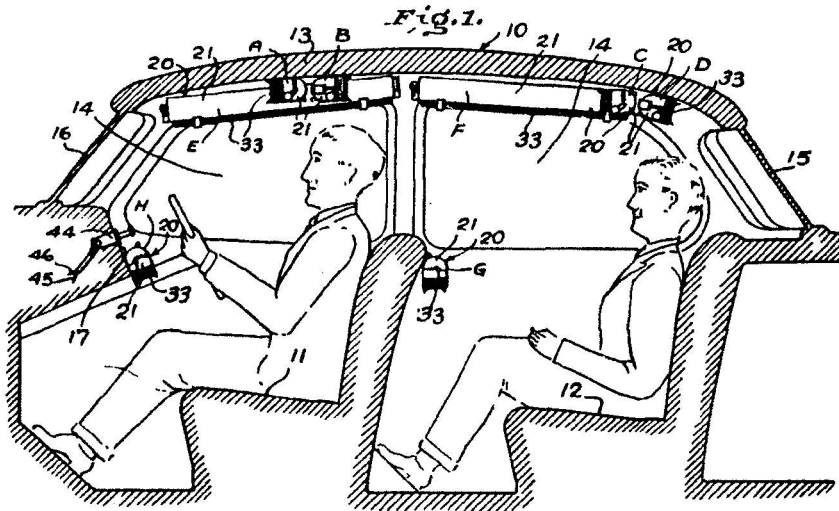
H. A. BERTRAND

2,834,606

SAFETY DEVICE FOR PASSENGERS

Filed Oct. 5, 1955

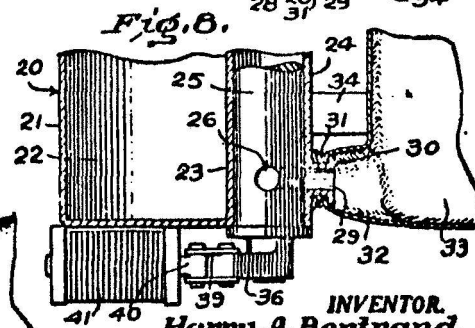
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2,834,606

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2,834,609

PASSENGER SAFETY DEVICE FOR VEHICLES

Harry A. Bertrand, Flint, Mich.

Application November 5, 1956, Serial No. 620,312

8 Claims. (Cl. 280—150)

The present invention comprises an improvement over my pending application Serial No. 538,748, filed October 5, 1955, and it consists in the combinations, constructions and arrangements of parts herein described and claimed.

Generally the present invention relates to a device, numbers of which may be mounted at convenient positions within a vehicle such as a motor vehicle and each of which consists of a casing within which is mounted a high pressure tank adapted to contain air under very high pressure and a novel bracket in which is compactly folded and held an inflatable bag. A novel valve arrangement is provided whereby the bag may be quickly and easily inflated to take its position between a passenger in the vehicle and the various solid portions of the vehicle which the passenger would normally come into violent contact in the case of a collision. The device may be set in motion by the simple closing of a switch convenient to the operator of the vehicle and novel means is provided for deflating the bag immediately after it has served its purpose whereby to eliminate any danger whatever of smothering the passengers with whom the inflated bag has come into contact.

It is accordingly an object of the invention to provide a novel safety device for vehicle passengers.

Still another object of the invention is to provide, in a device of the character set forth, a novel remotely controlled inflating valve.

Another object of the invention is to provide, in a device of the character set forth, a novel shut off valve automatically operable by the aforesaid inflating valve.

Still another object of the invention is to provide means for automatically opening the shut off valve after a bag, forming a part of the invention, has been fully inflated.

Still another and important object of the invention is the provision of a pilot valve for effecting the opening of the inflating valve.

Other and further objects of the invention will become apparent from a reading of the following specification taken in conjunction with the drawing, in which:

Figure 1 is a fragmentary longitudinal sectional view of a vehicle having an embodiment of the present invention mounted therein and showing an inflatable bag, forming part of the invention, in inflated condition.

Figure 2 is an enlarged end elevational view of the device embodying the present invention showing the same in inoperative condition.

Figure 3 is a further enlarged fragmentary sectional view taken substantially along line 3—3 of Figure 2 and showing the device in an active condition.

Figure 4 is a view similar to Figure 3 but showing the device as it would appear during inflation of the aforesaid bag, and

Figure 5 is a schematic view illustrating an electrical circuit utilized in the invention.

Referring more particularly to the drawing, there is shown therein a vehicle 10 provided with a seat 11, an instrument panel 12, a windshield 13 and doors 14. There is shown at 15 a passenger seated in the seat 11 and immediately above the windshield 13 there is affixed to the roof of the vehicle in any suitable manner a device embodying the present invention and generally indicated at 16.

The device 16 comprises a high pressure tank 17 adapted to contain air under high pressure and provided with a conventional filler opening 18 and cap 19.

A valve structure generally indicated at 20 is provided

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with a frame 21 which is affixed within the lower end of the tank 17 in any suitable manner as by welding 22. The frame is provided with a closed top 23 which is provided with a relatively large opening 24 in which is normally seated an inflating valve 25.

Extending downwardly from the underside of the wall 23 is a cylindrical member 26 provided at its upper end with a series of circumferentially spaced openings 27. The cylindrical member 26 has threadably connected to its lower end a bottom cover 28 in which is centrally mounted a bushing 29 through which vertically extends the stem 30 of a pilot valve 31 which is seated at the upper end of a centrally disposed passageway 32 in the valve 25. The passageway 32 continues downwardly through a cylindrical dependent portion 33 of the valve 25.

A housing 34 is integrally dependent from the wall 23, is open at its bottom and surrounds the moving portions of the valve structure 20. Pivotaly connected, as indicated at 35, to the inner wall of the housing 34 is a lever 36 and the lower end of the stem 30 is pivoted to the lever 36 as indicated at 37. A solenoid 38 is affixed to the underside of the wall 23 and is connected by a link 39 to the lever 36 in spaced relation to the outer end thereof and a compression spring 40 surrounds the solenoid and bears against the underside of the wall 23 and the upper side of the lever 36.

The housing 34 is provided with a foreshortened upper wall 41 at one side thereof providing a space 42 between the same and the underside of the wall 23. This space 42 connects with a passageway 43 which, in turn, connects with the atmosphere. In the wall 41, there is provided an opening 44 in which a valve 45 is adapted to seat. The valve 45 is connected to the outer end portion of the lever 36 by a link 46 and is provided with an upwardly extending guide member 47 which is slidably mounted in an upwardly extending guide housing 48 formed integrally with the upper side of the wall 23.

A pistonlike member 49, slidable in the cylindrical member 26 is provided with a cylindrical inner wall 50 which is slidable upon the extension 33 and is adapted to abut a shoulder 51 formed on the underside of the valve 25. Likewise, an outer wall 52, also on the pistonlike member is adapted to abut against a shoulder 53 formed adjacent the upper end of the member 26 and below said openings 27.

Affixed to the casing 17 is a plurality of dependent resilient bracket members 54 which are adapted to hold in folded condition an inflatable bag 55, as illustrated in Figures 2 and 3, the bag 55 being affixed upon the outer side of the housing 34 by means of a wire 56 or the like. To complete the device, there is provided a time delay switch 57 which may be mounted in any convenient position as, for example, upon the instrument panel 12 and which is attached by a wire 58 to a source of electrical energy 59 which is, in turn, connected by a wire 60 to the solenoid 38, a return wire 61 connecting the solenoid with the switch 57.

In operation, it will be apparent that when a collision is imminent and unavoidable in the judgment of the operator of the vehicle 10, in order to protect himself and his passengers from the ordinary effects of such collision wherein the bodies of the passengers and the driver are hurled against objects such as the instrument panel 12, the windshield 13, doors 14 or the like, it is only necessary for the operator to close the switch 57, thus energizing the solenoid 38. This action will move the lever 36 in a clockwise direction as viewed in Figures 3 and 4 pivoting the same upon the pivotal point 35. This action will lift the pilot valve 31 from its seat thus permitting the compressed air in the tank 17 to enter the passageway 32 whence it will be led to the underside of

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the member 49, the latter being normally spaced from the bottom of the member 28 by a shoulder 62 to thereby lift the member 49 which action will bring the member 50 into contact with the shoulder 51 of the valve 25 thereby opening the valve 25 and permitting an immediate outrush of air from the tank 17 through the openings 27 and thence into the bag 55 to quickly inflate the same and thereby protect the operator and passengers from the normal effects of a collision. During upward movement of the lever 36 to open the pilot valve 31 and prior to the opening of the valve 25, said lever moves the valve 45 into engagement with its seat at the opening 44 and thus prevents air, entering the bag 55, from escaping to the atmosphere. It will be apparent that if the valve 25 were not provided with the relatively small pilot valve 31, a great deal of pressure would be necessary to open the same. In the present instance, however, the high pressure within the tank 17 acts to lift the valve 25 from its seat to the position shown in Figure 4 to then permit the outrush of air, as above set forth. After a predetermined amount of time has elapsed and inflation of the bag 55 is no longer required, the time delay switch 57 opens the circuit to the solenoid 38, whereupon the spring 40 will act to move the lever 36 in a downward or counterclockwise direction as viewed in Figures 3 and 4 moving the various component parts to their position shown in Figure 3 and thus opening the valve 45 and permitting the air which was entrapped in the bag 55 to escape through the passage 42-43 to the atmosphere, thus relieving any pressure upon the persons protected during the actual collision and relieving them immediately of any danger of becoming smothered by such bag if the same were allowed to remain in an inflated condition.

While but one form of the invention has been shown and described herein, it will be readily apparent to those skilled in the art that many minor modifications may be made without departing from the spirit of the invention or the scope of the appended claims.

What is claimed is:

1. A device of the character described comprising an air pressure tank, an inflatable bag attached to said tank, a relatively large inflating valve interconnecting the tank and bag, and means operable by the pressure of air in said tank to open said inflating valve, said means including a cylinder mounted beneath said inflating valve exteriorly of said tank and having a plurality of relatively large openings therein communicating with the interior of said bag, a piston-like member that abuts said inflating valve when in raised condition, said inflating valve having a passageway therethrough communicating said tank with the space between the bottom of the cylinder and said piston-like member, a pilot valve seated at the upper end of said passageway, a stem for said pilot valve extending through said passageway and through the bottom of the cylinder, and means for opening said pilot valve.

2. A device as defined in claim 1 wherein said last-named means includes a lever pivotally connected to the lower end of said pilot valve stem, a solenoid connected to said lever, and remotely controlled electrical means for actuating said solenoid.

3. A device as defined in claim 2 wherein means is provided for relieving air pressure in said bag after a predetermined amount of time has elapsed since inflation of said bag.

4. A device as defined in claim 2 wherein means is provided for relieving air pressure in said bag after a predetermined amount of time has elapsed since inflation of said bag, said means comprising a passageway interconnecting the interior of said bag with the atmosphere, a valve connected to the free end of said lever and seated in said passageway, and a compression spring associated with said solenoid and adapted to urge said lever to its initial position upon de-energizing of said solenoid whereby to open said last-mentioned valve.

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5. A device of the character described comprising an air pressure tank, an inflatable bag attached to said tank, a relatively large inflating valve interconnecting the tank and bag, and means operable by the pressure of air in said tank to open said inflating valve, said means including a cylinder mounted beneath said inflating valve exteriorly of said tank and having a plurality of relatively large openings therein communicating with the interior of said bag, a centrally dependent portion on said inflating valve extending into said cylinder, a piston-like member surrounding said dependent portion and having an inner wall slidable on said dependent portion and adapted to abut said inflating valve when in raised condition, said inflating valve and its dependent portion having a passageway therethrough communicating the tank with the space between the bottom of the cylinder and said piston-like member, a pilot valve seated at the upper end of said passageway, a stem for said pilot valve extending through said passageway and through the bottom of the cylinder, and means for opening said pilot valve.

6. A device of the character described comprising an air pressure tank, an inflatable bag attached to said tank, a relatively large inflating valve interconnecting the tank and bag, and means operable by the pressure of air in said tank to open said inflating valve, said means including a cylinder mounted beneath said inflating valve exteriorly of said tank and having a plurality of relatively large openings in the upper end thereof communicating with the interior of said bag, a centrally dependent portion on said inflating valve extending into said cylinder, a piston-like member surrounding said dependent portion and having an inner wall slidable on said dependent portion and adapted to abut said inflating valve when in raised condition, a shoulder in the lower end of said cylinder for limiting downward movement of said piston-like member, said inflating valve and its dependent portion having a passageway therethrough communicating with the space between the bottom of the cylinder and said piston-like member, a relatively short outer wall for said piston-like member slidable upon the inner wall of said cylinder, a shoulder in said cylinder for limiting the upward movement of said piston-like member, a pilot valve seated at the upper end of said passageway, a stem for said pilot valve extending through said passageway and through the bottom of the cylinder, and means for opening said pilot valve.

7. A device as defined in claim 6 wherein said last-named means includes a lever pivotally connected to the lower end of said pilot valve stem, a solenoid connected to said lever, and remotely controlled electrical means for actuating said solenoid.

8. A device as defined in claim 7 wherein means is provided for relieving air pressure in said bag after a predetermined amount of time has elapsed since inflation of said bag, said means comprising a passageway interconnecting the interior of said bag with the atmosphere, a valve connected to the free end of said lever and seated in said passageway, and a compression spring associated with said solenoid and adapted to urge said lever downwardly to its initial position upon de-energizing of said solenoid whereby to open said last-mentioned valve.

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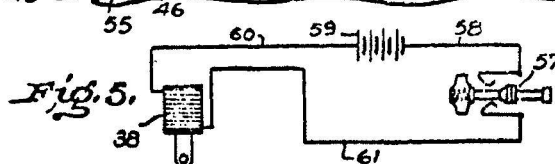
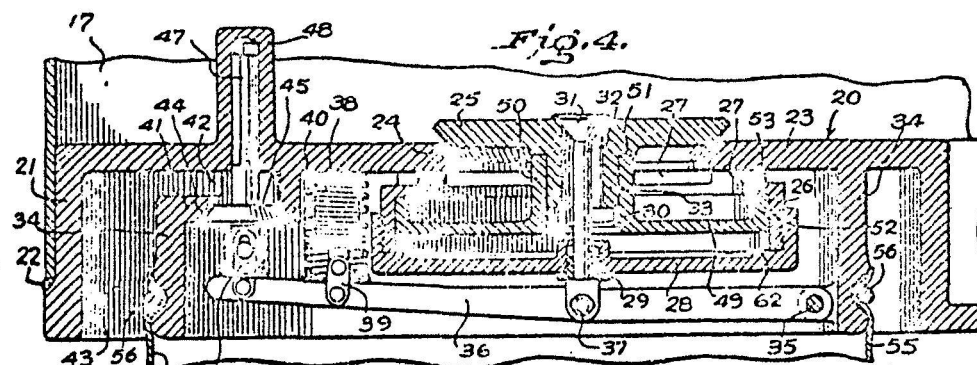
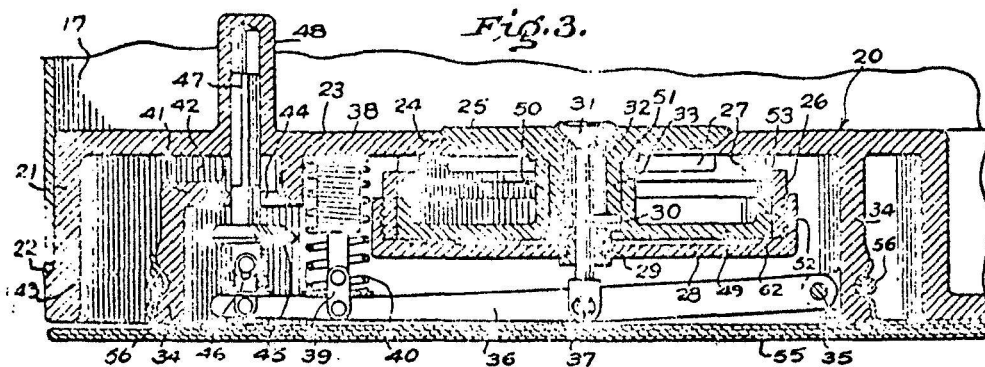
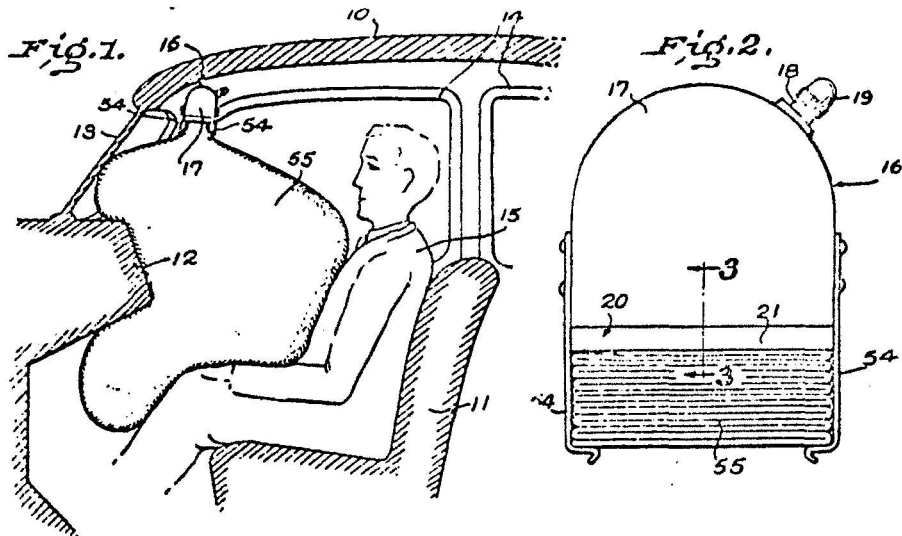
May 13, 1958

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2,834,609

PASSENGER SAFETY DEVICE FOR VEHICLES

Filed Nov. 5, 1956



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2,057,687

PNEUMATIC AIRPLANE SEAT

Frank G. Manson, Dayton, Ohio

Application August 16, 1935, Serial No. 36,543

6 Claims. (Cl. 155-179)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

The invention described herein may be manufactured and used by or for the government for governmental purposes, without the payment to me of any royalty thereon.

5 My invention relates generally to the construction of supports for the person and more particularly to a new and novel construction of pneumatic airplane chairs. In the past, airplane chairs have been constructed as simply as possible consistent with sturdiness in order to have a seat of the least possible weight with little or no concern as to the comfort of the passenger or his safety in case of a bad landing or crash. Bearing in mind the features lacking in the conventional design of airplane chair and also well knowing the necessity of the characteristics inherent in them, I have provided a type of chair incorporating not only lightness and sturdiness but in addition thereto safety and comfort.

20 The main object of my invention is to provide an airplane chair constructed of a plurality of gas-tight, non-communicating inflatable cells made from rubber inner-tubing, rubberized fabric, artificial rubber, or other similar material and filled with air or gas. With this construction, the entire chair cannot accidentally collapse should one cell become punctured or leaky. Also, according to my invention, each cell constitutes a bracing element for the cells adjacent to it, thereby eliminating the necessity for an outside or rigid frame.

35 A further object of my invention is to provide a cellular structural arrangement whereby the individual cells may be easily replaceable, as well as means for detachably connecting the chair as a whole to the floor, in substantially fixed relation.

40 Another object of my invention is to provide a chair formed of this character with a fabric strip or strips for maintaining the cells in assembled relation and for reinforcing the chair as a whole. This also serves to make the seat more attractive to the user.

45 Another object of my invention is the construction of a chair for an aircraft in which the seat portion of the structure is readily and easily adjustable to different heights. This makes the seat comfortable and at the same time permits the use of a parachute pack without inconvenience to the wearer.

50 A transport provided with a sufficient number of chairs of the above character will provide sufficient buoyancy to keep the airplane afloat in case of a forced landing of a land plane in water and in case the pontoons of a sea plane are damaged.

It is also readily apparent that when my form of chair is used in any vehicle, particularly an airplane, and one seat is immediately rearward of another, the forward seat will form a "crash pad" in case of an accident or forced landing.

With these and other objects in view, I shall now proceed with the description and drawings in which like parts are referred to by like numerals.

In the drawings:

Fig. 1 is a side view of an airplane, partially in section, incorporating my invention.

Fig. 2 is an assembled view of my seat in perspective.

Fig. 3 is a perspective view of one of the cellular structures of the chair.

Fig. 4 is a perspective view of another cellular structure of the chair.

Figs. 5 and 6 are perspective views of a pair of cellular structures that constitute the seat of the chair.

In Fig. 1 it will be seen how I intend to use my seat in the cabin of an airplane 2. It is also seen how, in placing one seat 3 immediately rearward of another seat 4, the forward seat forms a resilient pad for a person in the rearward seat in the case of sudden stopping of airplane due to a crash. It will also be seen that in the case of sudden vertical descent of an airplane, especially where the plane suddenly settles to the ground and "pancakes" or suddenly contacts the ground vertically, there will be sufficient shock absorbing in my type of seat to eliminate any ill effects to the persons in the aircraft due to the impact shock.

It is also apparent in Fig. 1 that by incorporating my chair in an airplane, especially in a transport, that my seats will provide sufficient buoyancy to be greatly in excess of the buoyancy provided in conventional pontoons of an aircraft.

Referring more particularly to Figs. 3 to 6, it will be seen that my chair is composed of a plurality of separate or individual collapsible cellular structures A, B, C, and D. Cells A and B constitute the seat cushion proper, both being of like dimensions throughout and being intended to be used in superposed relation with respect to one another. The total height of these cushions is to be the usual height for such seats. In the drawings it will be seen that cells A and B have "formers" 5a provided in them to "shape" the cells and keep them in a usable condition. These formers have holes or perforations provided in them of sufficient sizes to permit an easy flow of air there-through respectively.

Cell C constitutes the back portion of my chair and, as shown in the drawings, this cell is normally in a vertical position and rests at the bottom against the back vertical walls of cells A and B. The lower portion of this cell is of rectangular contour while the upper portion is formed to fit within an inverted U-portion of the cell D. The thickness of this cushion is much less than cushion A and B, but is similarly provided with "formers" 5a. These "formers" are also perforated to form a unitary structure.

Cell D, as shown in the drawing, is the frame of the chair and is of circular contour in cross-section. The base 7 of this cell is substantially of U-shaped contour and lies flatwise in a horizontal plane. When disposed in its normal horizontal position, the parallel sides of the U continue vertically as at 9 and bend horizontally as at 8 and lie in the vertical plane of the parallel sides of the U to form inverted L-shaped portions. The inverted L-portions continue vertically to form a vertical U-shaped portion 6 in the vertical plane of the bight, or base, of the horizontal U. This is all one cell and constitutes the frame portion of the chair, this frame portion substantially enclosing the cells A, B, and C. Cells A and B, as shown in Fig. 2, are contained between the horizontally disposed U-portion 7 and the inverted L-portions 8 and 9 of each side. Cushion C is substantially contained in and supports the inverted vertically disposed U-shaped portion 6 and rests upon the base of the horizontal inverted U-shaped portion 7. The inverted L-shaped portions form the arms of the chair 8 and the legs are formed by the base of the L as at A.

The cell D has a series of strips, as at 10, 11, 11a and 12, suitably attached thereto. These strips have button fasteners or other suitable quick attaching means on them to cooperate with the front strip of fabric 13 and the strip of fabric 14 on the sides and back. The strips 13 and 14 being detachably connected make it easily possible to replace the different cells of the seat structure. Although the strips are attached to the framelike cell D, it is easily conceivable they might be attached to the other cells.

Fig. 2 illustrates the chair in its assembled condition with the strip of fabric 13 attached to the strips provided on the legs 9, as described above, and substantially enclosing the front of the cushions A and B. This figure also shows fabric strip 14 attached to the strips provided on the base 7, legs 9, and attaching strip 11a on the back of U-shaped portion 6. This fabric strip 14 surrounds the sides and back of the chair and constitutes a reinforcing member or sling for the back.

As shown in Figs. 2 and 3 of the drawings, each of the cells A, B, C and D have individual valves 15, 16, 17 and 18, respectively, provided for separate inflation of each. As will also be seen in Fig. 2, this seat has a flap 19 provided around the bottom for easy attachment to the floor of an aircraft or other vehicle such as a train, motor bus, or even in a home. From the foregoing description, the ease with which the cell B may be removed or deflated for the convenience of a passenger or pilot having a parachute attached to his person, is readily apparent. It is also possible to adjust the resilience of the seat by increasing or decreasing the amount of air put into the seat cells A and B, or by valving the gas through valves 15 and 16. It is also readily apparent from the foregoing description, the ease with which my seat may be repaired, replaced or deflated and stowed away when not in use.

I claim:

1. In a chair a collapsible cellular frame structure formed of fabric material and having a horizontally disposed U-shaped portion, a vertically disposed inverted U-shaped portion arranged in the vertical plane of the bight of said first-mentioned U-shaped portion and inverted L-shaped portions connecting the legs of the first-mentioned U-shaped portion with the correspondingly arranged legs of the second-mentioned U-shaped portion, the upper and lower legs of said L-shaped portion serving as arm rests and legs respectively, a back-supporting structure between said U-shaped portions for supporting said U-shaped portions in spaced relation and a seat arranged between the inverted L-shaped portions and the back-supporting structure.

2. In a chair a collapsible cellular frame structure formed of fabric material and having a horizontally disposed U-shaped portion, a vertically disposed inverted U-shaped portion arranged in the vertical plane of the bight of said first-mentioned U-shaped portion and inverted L-shaped portions connecting the legs of the first-mentioned U-shaped portion with the correspondingly arranged legs of the second-mentioned U-shaped portion, the upper and lower legs of said L-shaped portion serving as arm rests and legs respectively, a back-supporting collapsible cellular structure between said U-shaped portions for supporting said U-shaped portions in spaced relation and a seat arranged between the inverted L-shaped portions and the back-supporting structure.

3. In a chair a collapsible cellular frame structure formed of fabric material and having a horizontally disposed U-shaped portion, a vertically disposed inverted U-shaped portion arranged in the vertical plane of the bight of said first-mentioned U-shaped portion and inverted L-shaped portions connecting the legs of the first-mentioned U-shaped portion with the correspondingly arranged legs of the second-mentioned U-shaped portion, the upper and lower legs of said L-shaped portion serving as arm rests and legs respectively, a back-supporting structure between said U-shaped portions for supporting said U-shaped portions in spaced relation, and a collapsible seat arranged between the inverted L-shaped portions and the back-supporting structure.

4. In a chair a collapsible cellular frame structure formed of fabric material and having a horizontally disposed U-shaped portion, a vertically disposed inverted U-shaped portion arranged in the vertical plane of the bight of said first-mentioned U-shaped portion and inverted L-shaped portions connecting the legs of the first-mentioned U-shaped portion with the correspondingly arranged legs of the second-mentioned U-shaped portion, the upper and lower legs of said L-shaped portion serving as arm rests and legs respectively, a back-supporting structure between said U-shaped portions for supporting said U-shaped portions in spaced relation, and a plurality of separate collapsible cellular structures arranged in superposed relation and between the inverted L-shaped portions and the back-supporting structure to form a seat portion.

5. In a chair a collapsible cellular frame structure formed of fabric material and having a horizontally disposed U-shaped portion, a vertically disposed inverted U-shaped portion arranged in the vertical plane of the bight of said first-mentioned U-shaped portion and inverted L-shaped portions connecting the legs of the first-men-

- tioned U-shaped portion with the correspondingly arranged legs of the second-mentioned U-shaped portion, the upper and lower legs of said L-shaped portion serving as arm rests and legs respectively, a back-supporting structure between said U-shaped portions for supporting said U-shaped portions in spaced relation, a reinforcing strip of flexible material surrounding and intimately engaging the back portion and the sides of said frame portion, the free ends of said strip being readily detachably connected to the legs of said frame portion and a collapsible seat interposed between the inverted L-shaped portions and the back-supporting structure.
6. In a chair a collapsible cellular frame structure formed of fabric material and having a horizontally disposed U-shaped portion, a vertically disposed inverted U-shaped portion arranged in the vertical plane of the bight of said first-mentioned U-shaped portion and inverted L-shaped portions connecting the legs of the first-mentioned U-shaped portion with the correspondingly arranged legs of the second-mentioned U-shaped portion, the upper and lower legs of said L-shaped portion serving as arm rests and legs respectively, a back-supporting structure between said U-shaped portions for supporting said U-shaped portions in spaced relation, a reinforcing strip of flexible material surrounding and intimately engaging the back portion and the sides of said frame portion, the free ends of said strip being readily detachably connected to the legs of said frame portion, a further reinforcing strip of flexible material arranged forward of said seat and between the legs of said frame portion and readily detachably connected thereto and a flexible cellular seat structure interposed between the L-shaped portions and the back-supporting structure.

FRANK G. MANSON. 20

20, 1936.

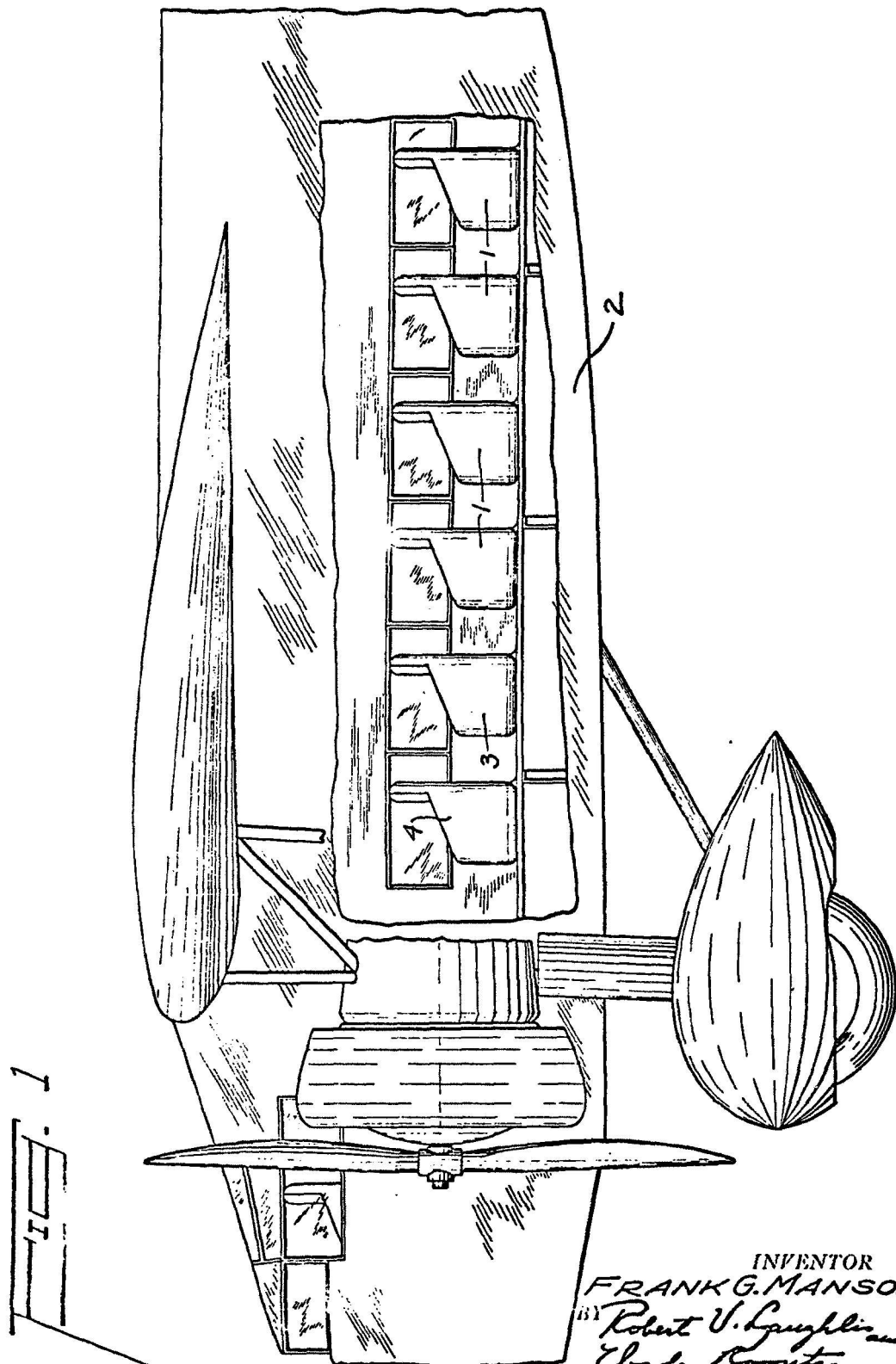
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2,057,687

PNEUMATIC AIRPLANE SEAT

Filed Aug. 16, 1935

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Oct. 20, 1936.

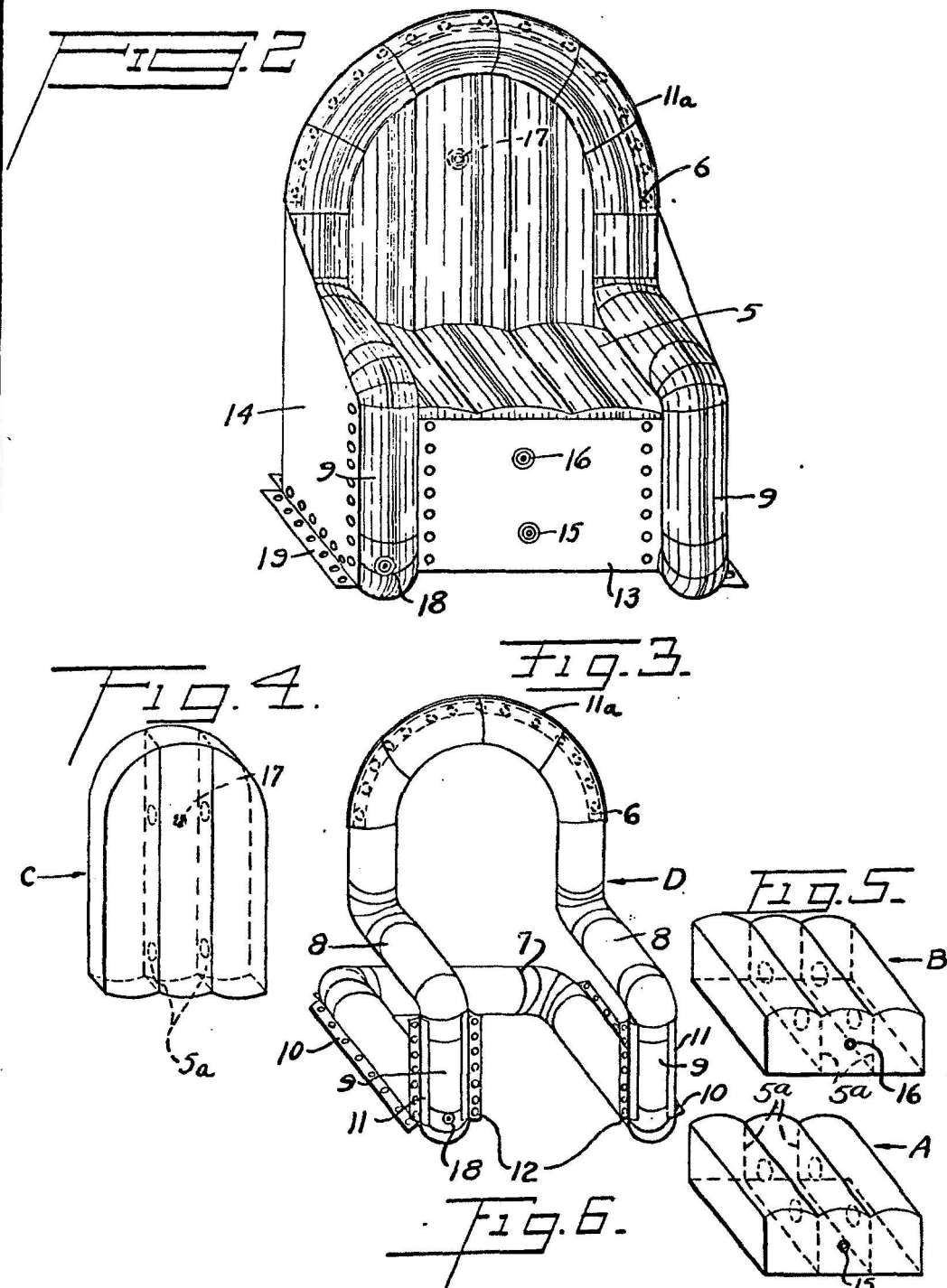
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2,057,687

PNEUMATIC AIRPLANE SEAT

Filed Aug. 16, 1935

2 Sheets-Sheet 2



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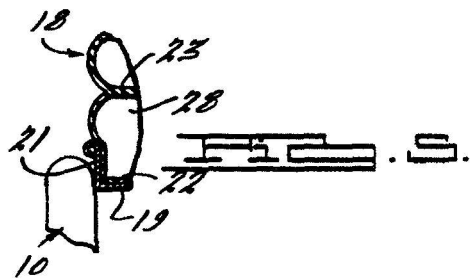
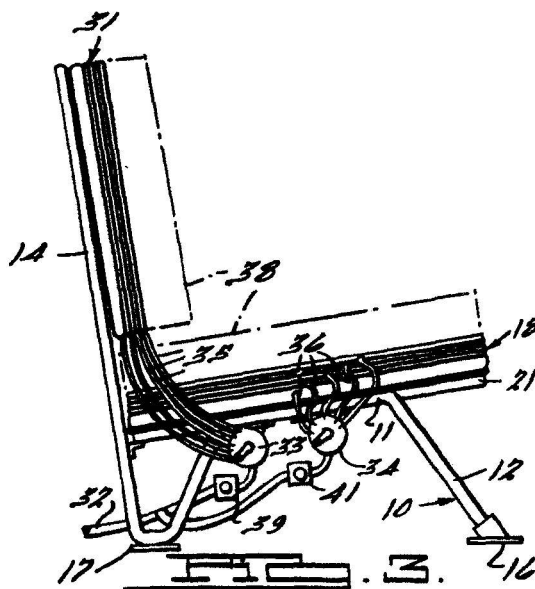
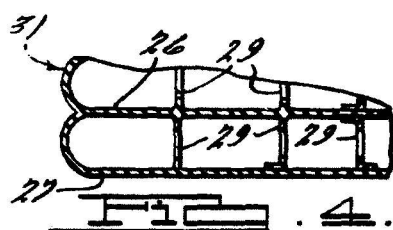
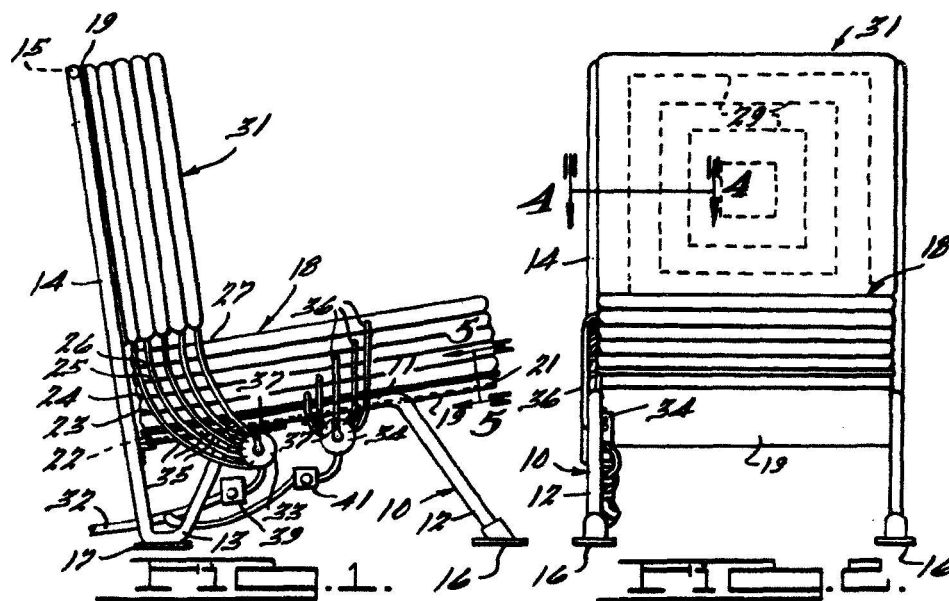
May 31, 1960

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2,938,570

SEAT CONSTRUCTION

Filed July 5, 1957



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1

2,938,570

SEAT CONSTRUCTION

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Filed July 5, 1957, Ser. No. 670,027

6 Claims. (Cl. 155—5)

This invention relates to seat structures and particularly to a seat structure having air cushions thereon by which the occupant may be adjusted vertically and horizontally toward and from the steering wheel of an automotive vehicle.

Supports have been provided for a seat heretofore which move the seat bodily in a horizontal and vertical direction for positioning the occupant of the seat relative to the steering wheel of the automotive vehicle.

The present invention produces a similar movement of the occupant in the horizontal and vertical planes relative to the steering wheel. This is accomplished by providing a seat and back cushion made of separate layers of a material impervious to the passage of air and controlling the inflation of the different compartments formed thereby. Thus, for example, if five compartments are provided to the cushion, the occupant will be positioned closer to the wheel in both the horizontal and vertical planes when all of the compartments are inflated. When the compartments are substantially one inch in thickness when inflated, the deflation of one of the compartments will cause the seat cushion to be lowered one inch and the back cushion to be retracted one inch from the steering wheel. This same result is produced when the support heretofore employed was moved downwardly and rearwardly one inch. By deflating others of the compartments, the occupant of the cushion will be lowered and permitted to move rearwardly and conversely, by inflating different compartments, the occupant is raised and moved forwardly. Different pressures may be provided on different compartments by the use of pressure regulating valves so that different degrees of firmness may be obtained. Settings may be provided on the valve to which the valve actuator is moved to inflate one or a plurality of the compartments to provide adjustment and a predetermined firmness. By moving the actuator to another position, the seat may be lowered and moved further rearwardly and the same, a greater, or less firmness provided thereto.

It is to be understood that the different compartments formed by the material impervious to the passage of air have interconnecting strips or webs between adjacent layers to prevent the layers from ballooning out, and retain the layers in substantially parallel planes irrespective of the amount of air delivered thereto.

The main objects of the invention are: to provide a seat and back cushion for a seat structure which have a plurality of compartments which are individually inflatable; to provide a seat structure having inflatable seat and back cushions which are adjusted to seat an occupant in a predetermined position relative to the steering wheel of an automotive vehicle; to provide a seat structure having a plurality of inflatable compartments with webs between the layers which provide communicating areas and means for limiting the separation of the layers when the compartments are inflated, and in general, to provide a seat structure which adjusts the oc-

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cupant in horizontal and vertical planes by the control of the supply of air thereto, all of which is simple in construction, positive in operation, and economical of manufacture.

Other objects and features of the novelty of the invention will be specifically pointed out or will become apparent when referring, for a better understanding of the invention, to the following description taken in conjunction with the accompanying drawing wherein:

Figure 1 is a view in side elevation of a seat structure having an inflatable seat and back cushion thereon embodying features of the present invention;

Fig. 2 is a front view in elevation of the seat structure illustrated in Figure 1;

Fig. 3 is a view of the seat structure illustrated in Figure 1 having the seat and back cushion thereof partially deflated;

Fig. 4 is an enlarged sectional view of the structure illustrated in Fig. 4, taken along the line 4—4 thereof;

Fig. 5 is an enlarged sectional view of the structure illustrated in Figure 1, taken along the line 5—5 thereof.

Referring to the figures of the drawing, the seat structure of the present invention embodies a base support 10, herein illustrated as being made from a tube provided with a central section 11 and forward and rearward leg portions 12 and 13. The leg portion 13 may have an upwardly extending back supporting section 14 joined thereto, the two sections being connected at the top by a bridging section 15 forming an inverted U-shaped structure for the support of the back cushion. A securing foot 16 is provided on the end of the forward leg portions 12 and a securing foot 17 is attached to the rear leg portion 13 at the junction with the back supporting sections 14.

A seat cushion 18 is supported by the central portions 11 of the seat supporting elements 10 at opposite sides of the seat structure and by the brackets on the back sections 14. The support embodies a platform 19 which may be constructed in any manner, but as clearly illustrated in Fig. 5, is made from a sheet of metal having a flanged edge 21 for receiving the bottom portion of the cushion 18. The material of the cushion is secured to the platform preferably by suitable bonding material such as "Cycleweld" and the like, which are known in the art to be suitable for this purpose. It is to be understood that the supporting platform 19 may be made from a sheet of reinforced resin material which readily bonds to the material of the seat cushion, or which may be made a part thereof during the molding process. Several layers of resin impregnated canvas, when secured together by heat and pressure, would provide such a reinforced platform.

The seat cushion 18 has a plurality of layers 22, 23, 24, 25, 26 and 27. The pair of adjacent layers forms a compartment such as compartment 28, formed by the layers 22 and 23. Webs 29 are provided between the various layers 22 and 23, 23 and 24, 24 and 25, 25 and 26, and 26 and 27 for the purpose of maintaining the various layers in substantially parallel relation to each other when inflated. It is to be understood that the webs have openings therein or are spaced apart at different points to have all of the areas of the compartments freely communicating with each other.

A back cushion 31 has the same construction as the seat cushion 18, being mounted on a platform 19 which is secured to the back sections 14 by suitable means, as by welding the platform, if made of metal, by having a pocket formed on the back layer which extends downwardly over the inverted U-shaped sections 14 and 15, or which may have tabs which are secured to the back sections by suitable screws or bolts.

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An air delivery line 32 is connected to a pair of valves 33 and 34. The valve 33 is connected by tubes 35 to the individual compartments of the back cushion 31, while tubes 36 connect the compartments of the seat cushion 18 to the valve 34. By operating the actuating handles 37 of the valves, any number of the compartments of the seat and back cushions may be inflated. Thus, as seen in Figure 1, all of the compartments are inflated, while in Fig. 3 only the bottom valve compartment 28 is inflated. It will be noted from the dotted lines 38 the amount that the occupant had been lowered and moved backwardly in the seat. Thus, through the inflation of the various compartments of the seat, the occupant may be raised and moved forward or lowered and moved backwardly any desired amount, to be disposed in a desired position relative to the steering wheel of an automotive vehicle.

A pressure regulating valve 39 may be provided in the line to the valve 33 and a pressure regulating valve 41 may be provided in the line to the valve 34. By this means, the pressure on the seat and back cushion may be independently adjusted to produce the desired firmness for the depth of the cushions employed for each individual occupant. The valves 33 and 34 are preferably connected to the tubes 35 and 36 in such manner that in one position the first compartment 28 would be inflated, in another position the next compartment would be inflated, and so on until all of the compartments of each of the cushions are inflated. Similarly, the pressure on the back and seat cushion may be independently adjusted to regulate the firmness of the resulting cushion. It is within the purview of this invention to employ a regulating valve for each of the interconnecting tubes 35 and 36, permitting them to be individually adjusted so that the different pressures may be employed for the air in any of the compartments. Such an arrangement produces a desired firmness to the cushions, while permitting the cushions to contour and provide the desired seating comfort for the occupant.

It is to be understood that by plurality of compartments, two or more of the compartments will produce satisfactory results. At least one of the compartments would be employed for changing the distance between the occupant and the wheel of the automotive vehicle, and at least one other of the compartments would be employed for producing firmness.

It is to be understood that any type of valve could be employed. A single valve could be utilized for controlling the pressure in any or all of the compartments in the seat and back cushion, as well as the pressure on the air in any of the compartments. Such a single valve would simplify the control for positioning the occupant of the seat structure.

What is claimed is:

1. In a seat construction, a base support for a seat cushion, a back support for a back cushion, a seat cushion on said base support having a plurality of compartments disposed one above the other, a back cushion on said back support having a plurality of compartments one before the other, and means for selectively inflating said compartments to regulate the height and forward position of the seat occupant.

2. In a seat construction, a base support for a seat cushion, a back support for a back cushion, a seat cushion on said base support having a plurality of compartments disposed one above the other, a back cushion on said back support having a plurality of compartments one before the other, means for selectively inflating said compartments to regulate the height and forward position of the seat occupant, a platform secured to said seat and back supports, and means for securing said seat and back cushions to said platforms.

3. In a seat construction, a base support for a seat cushion, a back support for a back cushion, a seat cushion on said base support having a plurality of compart-

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ments disposed one above the other, a back cushion on said back support having a plurality of compartments one before the other, means for selectively inflating said compartments to regulate the height and forward position of the seat occupant, a platform secured to said seat and back supports, means for securing said seat and back cushions to said platforms, a plurality of tubes individually connected to the compartments of said seat and back cushions, a pair of valves connected to the tube of said respective cushions, and an air supply line connected to said valves which controls the inflation of the compartments of said cushions.

4. In a seat construction, a base support for a seat cushion, a back support for a back cushion, a seat cushion on said base support having a plurality of compartments disposed one above the other, a back cushion on said back support having a plurality of compartments one before the other, means for selectively inflating said compartments to regulate the height and forward position of the seat occupant, a platform secured to said seat and back supports, means for securing said seat and back cushions to said platforms, a plurality of tubes individually connected to the compartments of said seat and back cushions, a pair of valves connected to the tube of said respective cushions, an air supply line connected to said valves which controls the inflation of the compartments of said cushions, and pressure regulating valves in said air supply line for controlling the amount of pressure on the air in said compartments.

5. In a seat construction, a seat frame, a seat cushion on said frame having a plurality of layers of compartments one above the other, a back cushion on said frame having a plurality of layers of compartments one before the other, a plurality of tubes connected individually to the compartments of the back cushion, a valve to which said tubes are connected, additional tubes connected to the compartments of said seat cushion, a valve to which said tubes are connected, and a supply line for air connected to said valves, said valves controlling the number of compartments which are inflated to regulate the height and forward position of the seat occupant.

6. In a seat construction, a seat frame, a seat cushion on said frame having a plurality of layers of compartments one above the other, a back cushion on said frame having a plurality of layers of compartments one before the other, a plurality of webs interconnecting the adjacent layers of the compartments of the seat and back to maintain the layers in substantially parallel relation to each other when inflated, a plurality of tubes connected individually to the compartments of the back cushion, a valve to which said tubes are connected, additional tubes connected to the compartments of said seat cushion, a valve to which said tubes are connected, a supply line for air connected to said valves, and pressure regulating valves in the supply lines to said valves, said valves controlling the number of compartments which are inflated to regulate the height and forward position of the seat occupant.

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